Duwamish Groundwater Studies

METRO

May 1985

Municipality of Metropolitan Seattle

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SEA140919

Sweet, Edwards & Associates, Inc.
Ground Water, Waste Disposal, Engineering Geology & Drilling Services
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May 13, 1985

Mr. Tom Hubbard
Municipality of Metropolitan Seattle
Exchange Building
821 Second Avenue
Seattle, WA 98104

RE: FINAL REPORT - DUWAMISH GROUND WATER STUDIES

Dear Mr. Hubbard:

Sweet, Edwards & Associates, Inc. is pleased to submit ten copies or our final report "Duwamish Ground Water Studies."

Thank you for giving us the opportunity to work with you and the Municipality of Metropolitan Seattle on this very interesting project. I hope we can be of further service to you in the future.

Respectfully submitted,

SWEET, EDWARDS & ASSOCIATES, INC.

Larry West

LARRY WEST
Associate Geologist

tls

Enclosures: 10 copies of report

DUWAMISH GROUND WATER STUDIES

MAY 13, 1985

SUBMITTED TO:

MUNICIPALITY OF METROPOLITAN SEATTLE
821 SECOND AVENUE
SEATTLE, WA 98104

SUBMITTED BY:

SWEET, EDWARDS AND ASSOCIATES, INC.
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SEATTLE, WA

DUWAMISH

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SECTION I
EXECUTIVE SUMMARY

The purpose of this investigation was to determine what investigations and costs would be required to determine contaminant contribution to the Duwamish River from ground water inflow between the Black River and Elliott Bay. Our approach to the project included collection, review, evaluation of the existing data, and development of a monitoring strategy.

DATA SEARCH

A review of published and unpublished reports on geology, ground water, surface water, land use, and documented contaminant sources was performed. In addition, 31 people were contacted in 17 government agencies to secure additional information on the study area. Twenty-nine companies with operations in the Duwamish River Valley were also contacted.

A study of waste disposal practices and the dredge/fill history in the Duwamish Valley was conducted by Harper-Owes. Fifty-five potential sources of pollution were identified in the basin. A wide range of inorganic and organic constituents were identified which are potential ground water contaminants.

We also performed an evaluation of six existing ground water contamination studies conducted in the Duwamish River Valley.

The most useful subsurface information available were boring logs from the west Seattle bridge construction, METRO Renton Effluent Transfer System Project and boring logs on file with the City of Seattle Department of Engineering.

In general, the quantity and quality of available industrial waste characterization information are adequate to determine the range of potential ground water contaminants. However, there is little or no ground water hydrology or water quality data, which is required to determine toxicant inflow to the river.

HYDROGEOLOGY

Urban development, industrialization, a complex storm sewer system, and river tidal effects result in a complex shallow ground water flow system in the Duwamish Valley. The subsurface geology of the Duwamish Valley includes surficial fill (predominantly sand, silty sand, and silt dredge spoils) throughout most of the northern two-thirds of the valley floor (5-40 feet deep). Fine grained river and lake sediments underlie the fill and are in turn underlain by glacial till, sand, and gravel. Glacial deposits also form the valley walls and uplands. In the southern and eastern part of the valley, the uplands are dominated by sedimentary bedrock (siltstone and sandstone) and igneous intrusives (andesite).

No regional ground water studies of the Duwamish Basin have been done. Ground water recharge is primarily via infiltration of precipitation and subsurface inflow from glacial upland aquifers. Subsurface flow also enters the basin via bedrock fractures and the alluvium at the southern boundary of the study area.

Two major components to ground water flow are suspected, shallow flow in the fill and near surface sediments, and a deeper component in the underlying alluvial and glacial deposits. Deeper flow is generally sub-parallel to the valley axis and the river, discharging into Elliott Bay.

Shallow ground water flow is primarily to the river, altered over short distances by zones of preferential flow (filled river meanders). Both the direction and rate of ground water flow is significantly influenced by river levels and tidal fluctuations.

Ground water quality and the concentration of contaminants are influenced by the attenuation properties of the fine grained sediments in the valley floor. Changes in ground water chemistry at the fresh/salt water interface near the river may affect solute mass transport of ground water contaminants to the river.

GROUND WATER MONITORING STRATEGY

The available data indicate a high potential for ground water pollution, particularly for mobile inorganics such as arsenic and for chlorinated hydrocarbons. Three monitoring program alternatives were developed.

Alternative A: Grid

Alternative A is the most comprehensive program and consists of 151 ground water monitoring wells on 1500 foot grid spacings, 16 upland wells and three river level monitors. The cost for installation and the first two years of sampling and testing would be approximately $2,200,000.

The major disadvantage, other than the high cost, would be the location of many of the monitoring wells on private property, where access may be difficult or impossible to obtain. The main advantage of Alternative A would be sufficient data to determine total contaminant loading to the river and the primary contaminant source areas.

Alternative B: Point Source

This alternative would focus on the monitoring of identified potential contaminant sources identified in the basin. A total of 112 monitoring wells would be required and three river level recorders. The cost for installation and the first two years of sampling would be about $1,700,000.

The major disadvantage of this alternative is the reduced ability to account for nonpoint and unidentified contaminant sources. In addition, this approach provides for little flexibility in monitoring well locations and without full implementation would not provide sufficient data to determine total toxicant contribution to the river.

The major advantage of this program would be the identification of existing contaminant sources.

Alternative C: Cross Channel

The Cross Channel alternative focuses on determining the hydrology of the shallow ground water and estuarine flow system and a general characterization of the basin's ground water quality. This alternative includes 61 monitoring wells and six river level monitors. The cost for installation and the first two years of monitoring would be about $935,000.

The major disadvantage of this approach would be the system's inability to detect specific sources of contamination. The major advantages of the Cross Channel alternative are comparatively low cost, sufficient data to estimate existing contaminant contribution to the river via ground water, and the development of a data base suitable for design of more comprehensive monitoring programs if necessary in specific basin subareas.

RECOMMENDATIONS

We recommend Alternative C: Cross Channel Monitoring as the preferred alternative because of its lower cost and flexibility. Alternative C could be implemented in two or more phases. The first phase would provide sufficient information to focus, and possibly reduce, subsequent phase costs. Total cost of Phase I would be about $461,000.00 for the first two years.

We also recommend that a study of contaminant solute mass transport across the subsurface fresh/salt water interface be performed. The applicability of this portion of the study to industrialized estuarine systems nationwide makes this type of applied research potentially grant eligible.

SECTION II
INTRODUCTION

This section describes the project goals, scope of work, sources of information, and study organization on which we based our investigation.

The purpose of this study was to determine what investigations and costs would be required to determine contaminant contribution to the Duwamish River from ground water between the Black River and Elliott Bay (see Figure II-1 - Study Area Location Map).

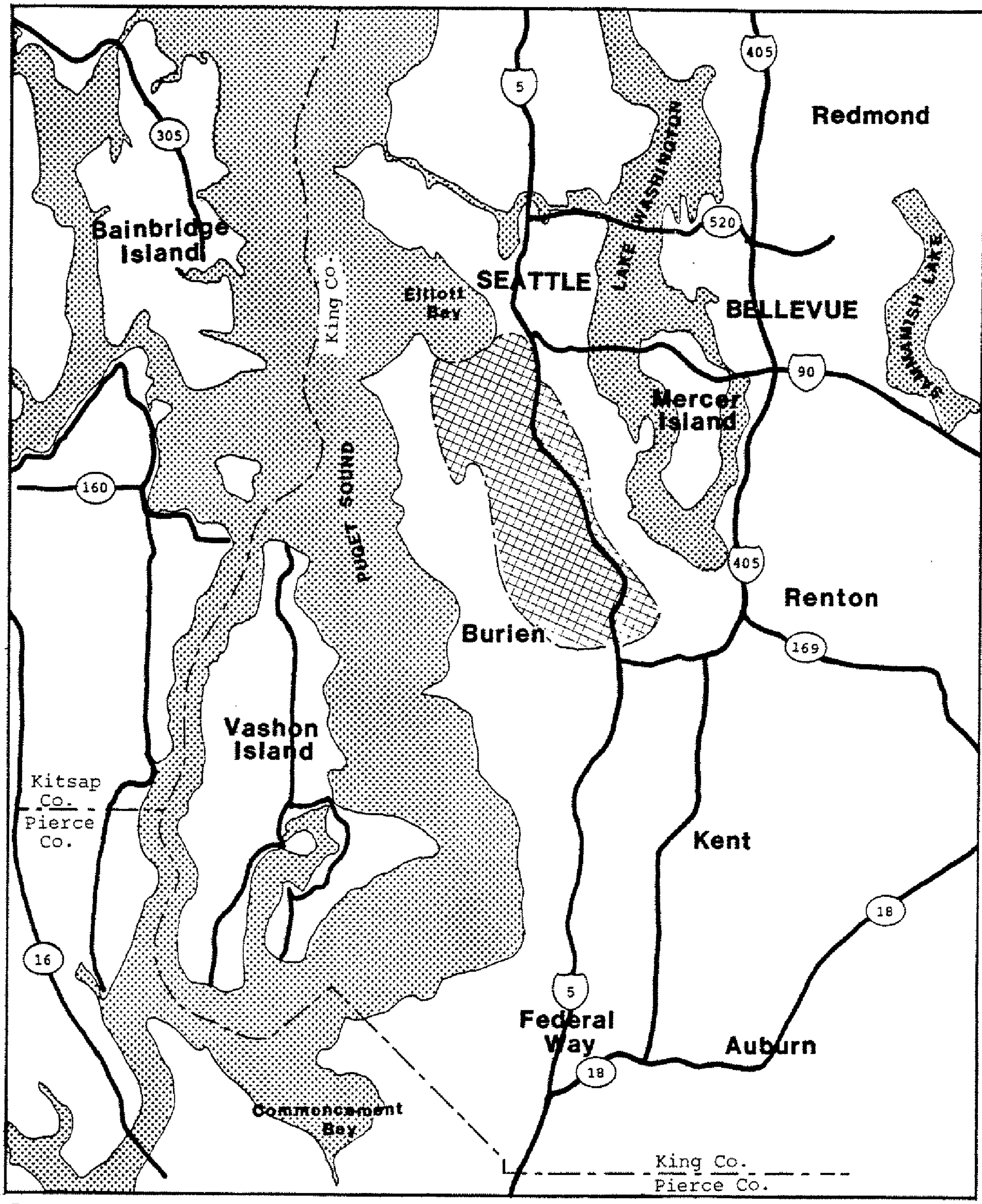
PROJECT GOALS

1. Provide a general characterization of the surface water and ground water regime along the Duwamish River between Black River and the mouth of the East and West waterways.
2. Identify or define preliminary hydrogeologic parameters relevant to the determination of contaminant loading to the river (i.e., aquifer/estuarine hydrology, aquifer permeability, water quality, etc.).
3. Identify graphically (maps, cross sections, schematics, etc.) the location and type of available data and information.
4. Identify data and information gaps as well as apparent deviations from the general river characterization.
5. Develop a ground water quality monitoring and analysis strategy.

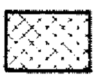
SCOPE OF WORK AND AUTHORIZATION

In line with the above objectives, the following scope of work was authorized in our contract of November 1, 1984, with the Municipality of Metropolitan Seattle.

Task 1 - Data Review
This task included five subtasks:
- 1a. Literature Search
- 1b. General Data Review
- 1c. Waste Disposal Practices Review



Base Map: U.S.G.S. Seattle, Washington.



Study Area

0 4 8

Scale in Miles

DUWAMISH GROUND WATER STUDIES
Study Area Location Map

Sweet, Edwards & Associates

	INITIALS	DATE
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Figure II-1

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1d. Review River Dredge and Fill History
1e. Review Existing Ground Water Contamination Studies

Task 2 - Develop Preliminary Conceptual Ground Water Model
Task 3 - Develop Ground Water Monitoring and Analysis Strategy
Task 4 - Project Management
Task 5 - Report Preparation

More effort was required than anticipated for the data collection tasks. Because of this and the lack of existing basin hydrology data, less effort was expended on the development of a conceptual ground water model.

SOURCES OF INFORMATION AND ACKNOWLEDGEMENTS

Sources of information included published and unpublished reports on geology, ground water, surface water, water quality, documented contaminant sources, and land use, as well as interviews with individuals from government agencies and private industries. The individuals who have contributed information are too numerous to list here and are named later in this report. However, we would like to extend special thanks to representatives of METRO, the Environmental Protection Agency, Washington Department of Ecology, Department of Social and Health Services, Corps of Engineers, Port of Seattle, Seattle Engineering Department, and the Duwamish Industrial Council.

STUDY ORGANIZATION AND APPROACH

Following is a brief overview of the approach and procedures undertaken to complete the scope of work.

Task 1 - Data Review

Appendix A presents a comprehensive bibliography of the available published and unpublished reports reviewed for this study. Most subsurface information is available from borings drilled for foundation studies. The studies conducted for the West Seattle Bridge and Renton Effluent Transfer Systems Duwamish Alignment provide considerable amounts of data useful to the project in the areas where they were conducted. Most of the basin subsurface geology was interpreted from borings on file with the Seattle Department of Engineering. Very little relevant ground water data was uncovered during the data collection process.

A list of private companies and organizations contacted is presented in Appendix C.

A study of waste disposal practices and dredge and fill history was performed by Harper-Owes as part of this investigation and is presented in Appendix D. This study identifies potential sources of contamination to the Duwamish basin's ground water.

Task 2 - Develop Conceptual Ground Water Model

A conceptual ground water model is the geologist's interpretation of the physical and dynamic nature of a ground water system. In essence, the model represents the geohydrologic regime impacted by contamination.

Due to the lack of ground water flow and quality data, the model developed for this study is limited to delineation of surface and subsurface sediments and broad assumptions on the ground water flow within the basin.

The distribution of sediments within the basin was determined using several hundred boring logs drilled primarily for foundation investigations in the basin. These borings were drilled and logged by a wide variety of geotechnical and engineering firms including:

Converse Consultants	North American Inspection & Testing
Metropolitan Engineers	Geo/Resources Consultants Inc.
Walter Lumm Assoc., Inc.	Neil H. Twelkev & Assoc.
Shannon and Wilson, Inc.	Rittenhouse-Zeman & Assoc.
Hart Crowser and Assoc.	Seattle City Dept. of Engineering
CH2M Hill	Washington Dept. of Highways
Harding Lawson Assoc.	U.S. Army Corps of Engineers
Dames and Moore	Sweet, Edwards & Assoc., Inc.

Because subsurface materials classification and interpretation varies substantially, depending on the investigator and the objectives of a specific project, it was considered neither practical nor desirable to attempt correlation of specific lithologically described units noted in the boring logs. Therefore, the subsurface units were defined based on aquifer properties, such as permeability, and on contaminant attenuation capacity of the sediments.

The major subsurface unit classification includes:

Material Type	Relative Attenuation Capacity
1. Gravel Sand & Gravel	Very Low
2. Sand	Low
3. Silty Sand Sandy Silt Silt & Sand	Moderate
4. Silt & Clay	High
5. Organic Materials (i.e., peat)	Very High
6. Glacial Till	Moderate to High

Cross sections presented in section IV illustrate the general distribution of these materials in the basin's subsurface.

The available data indicate that ground water flow patterns along the Duwamish are very complex. This complexity is due to the distribution of fill and alluvial sediments, and the influence of storm drains and tides. The river tides have a direct and near immediate effect on the rise and fall of ground water levels as far as 13 miles up river from Harbor Island.[1] In specific areas, such as at the Boeing-Isaacson property near the center of the study area, tidal fluctuations of several feet cause diurnal reversal of ground water flow direction in the shallow aquifer within 500 feet of the river.[2]

Ground water flow elements considered within the conceptual model include general assumptions on shallow and deep ground water flow direction, and areas of preferential flow (i.e., abandoned river channels). The information derived from the conceptual model relevant to design of a ground water monitoring strategy is presented in sections III and IV.

Task 3 - Develop Ground Water Monitoring and Analysis Strategy

Considering the limited data available, a major data collection effort will be required to design and implement an effective ground water monitoring program. Our approach to determining what data is required, lacking and available, was to employ the monitoring methodology outlined by the Environmental Protection Agency's (EPA) Environmental Monitoring and Support Laboratory[3] as a checklist.

The EPA methodology is particularly suited for the Duwamish Basin in that it is primarily directed toward source monitoring, which focuses on measurements relating to pollution and methods of waste disposal contributing to pollution. The EPA's monitoring methodology includes these 15 steps.

1. Select area or basin for monitoring
2. Identify potential pollution sources, causes, and methods of waste disposal.
3. Identify potential pollutants
4. Define ground water usage
5. Define hydrogeologic situation
6. Study existing ground water quality
7. Evaluate infiltration potential for wastes at the land surface
8. Evaluate mobility of pollutants from the land surfaces to the water surface
9. Evaluate attenuation of pollutants in the saturated zone
10. Prioritize sources and causes
11. Evaluate existing monitoring methods
12. Establish alternative monitoring approaches
13. Select and implement the monitoring program
14. Review and interpret monitoring results
15. Summarize and transmit monitoring information

It is important to point out however, that the goal of the EPA methodology is to develop a monitoring program that "detects changes in the environment," while the specific goal of this study is to develop a program which will "determine contaminant contribution to the Duwamish River due to ground water inflow." Therefore, the above 15 steps were given varying emphasis in the present study. The Monitoring Strategy is presented in detail in Section V.

SECTION III
STUDY AREA CHARACTERISTICS

This section, and Section IV - Valley Floor Characteristics, summarize our understanding of the project area and serves as a basis for developing a ground water monitoring strategy.

SURFICIAL FEATURES AND DEVELOPMENT

The Duwamish Valley covers approximately twenty-nine square miles and is located in western King County. The study area extends from Elliott Bay on the north to the Black River on the south (see Figure III-1 - Study Area Map). The east boundary of the study area is the topographic divide separating the Duwamish Valley from the Lake Washington drainage basin. The western boundary is the topographic divide separating the valley from west Seattle drainage to Puget Sound.

Physiography

Physiography influences the direction of shallow ground water movement. Due to the lack of hydrology data, most of the assumptions about ground water flow are based on physiography and topography. The valley was originally excavated by ice scour during the last glaciation (about 15,000 years ago). It was subsequently flooded by marine waters after retreat of the ice sheet, and the combined processes of isostatic rebound and fluvial aggradation to base level left the valley as we see it today. The upland portion of the valley is formed by the slopes of a glacial drift plain. The western upland rises to elevations of 400 to 500 feet while the eastern upland rises to about 300 feet elevation.

The valley floor occupies about 40 percent (12 square miles) of the study area and elevations are generally less than 20 feet above sea level.

Surface Drainage

The Duwamish Estuary is the dominant surface water feature in the basin and begins approximately at the confluence of the Black and Green Rivers. The Duwamish winds its way north about 12 miles to Elliott Bay. The lower portions of the estuary have been substantially altered over time by dredge and fill activities (see Harper-Owes detailed account of dredge-fill activities in Appendix D). Flow in the Duwamish is controlled by release at Howard Hanson Dam and diversions from the Green River. River discharge into the valley is less than 12,100 cubic feet per second, approximately two-thirds of which exits to Elliot Bay via the West Water Way, the other third via the East Water Way.[4,5]

The Duwamish, as with many estuarine environments, is characterized by a stratified two-layer flow, with a salt water wedge moving inland beneath fresh water flowing toward Elliott Bay. This salt water wedge has been observed ten miles upriver during high tides and low river flows. Tidal fluctuations of river stage have been observed well past the southern boundary of the study area.

Surface drainage of precipitation in the study area is almost completely controlled by manmade drainage improvements diverting runoff to storm drainage systems or sewers.[6]

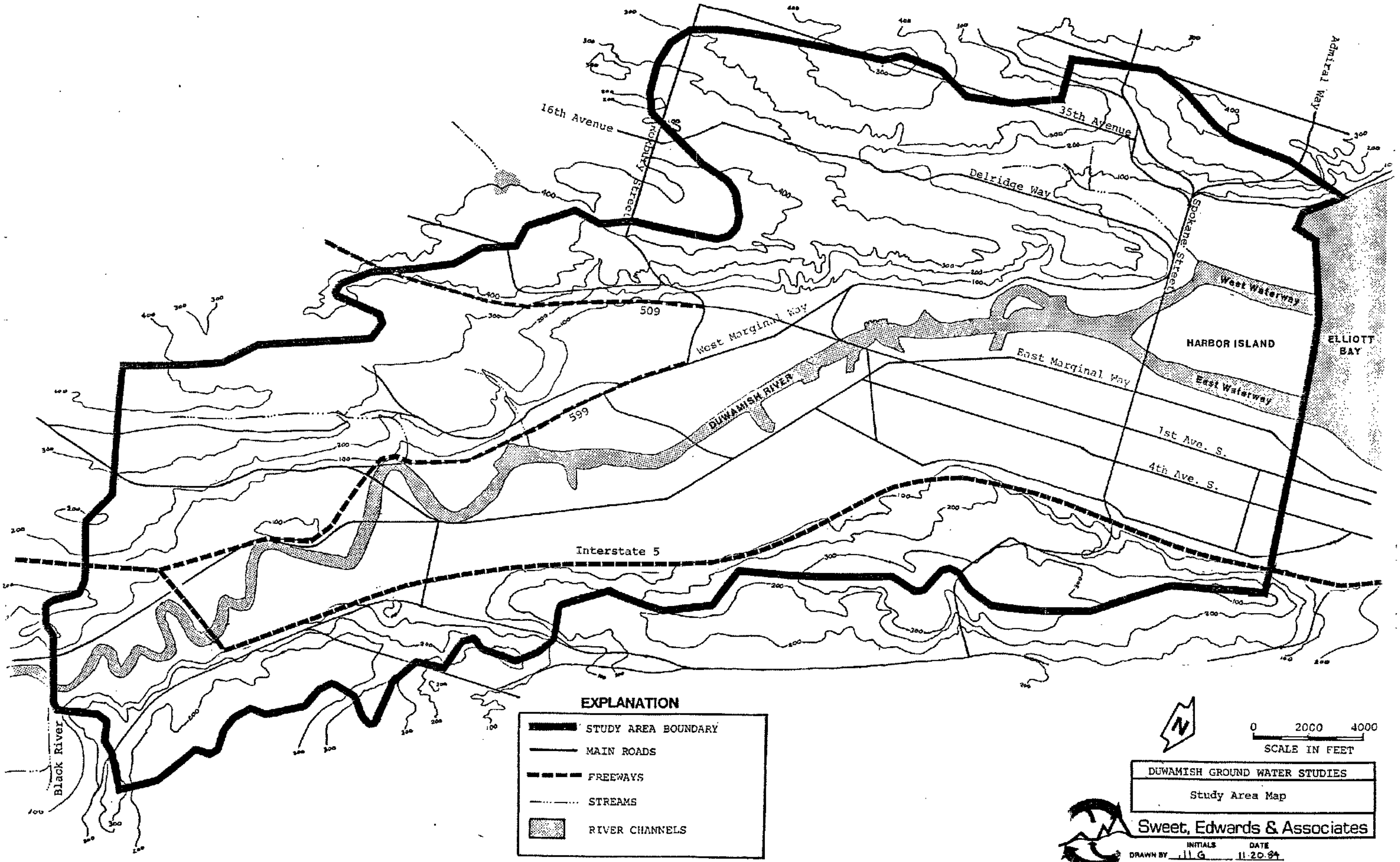
Climate

The temperate marine climate of the Duwamish Valley is characterized by relatively mild, wet winters and cool, dry summers. Weather data collected just outside the study area at Seattle-Tacoma Airport indicates mean annual precipitation is 38.59 inches. As Figure III-2 - Precipitation for Sea-Tac Airport illustrates, December is usually the wettest month and July the driest. Approximately 67 percent of the annual rainfall occurs in the five month period from November through March. Figure III-2 also shows the annual precipitation and the cumulative departure from the yearly mean for the period 1945-1984. A rising line on the cumulative departure curve indicates a period of above average precipitation and a falling line indicates below average precipitation. Both graphs indicate that total annual rainfall has been less than average during most of the period 1975-1984.

The annual mean temperature at Seattle-Tacoma airport is 51.1° F. The highest mean temperature, about 65° F, occurs in August, and the lowest mean, about 38°, occurs in January.

Development and Land Use

Land use is an important consideration in the design of a ground water monitoring program. Land use type affects the amount of



Base Map: U.S.G.S. 7½' Quad. Duwamish Head, Seattle South & Des Moines

DUWAMISH GROUND WATER STUDIES

Study Area Map

Sweet, Edwards & Associates

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Figure III-1

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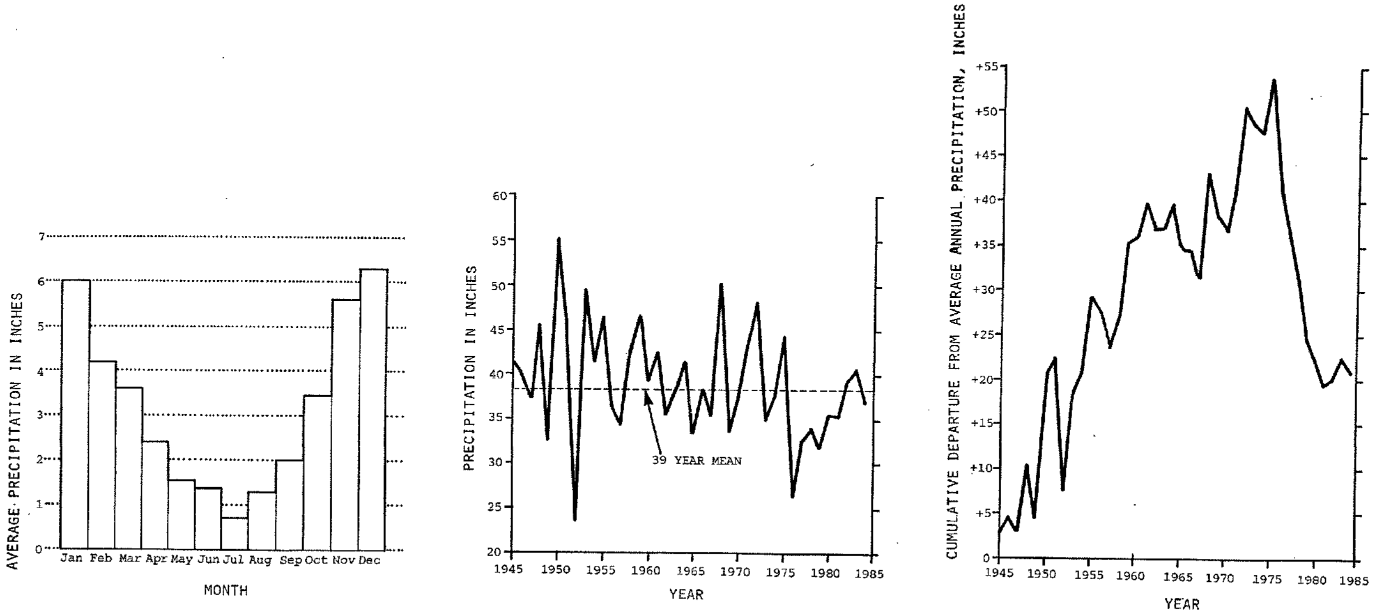

DUWAMISH GROUND WATER STUDIES
Precipitation for Sea-Tac Airport

Sweet, Edwards & Associates

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Figure III-2

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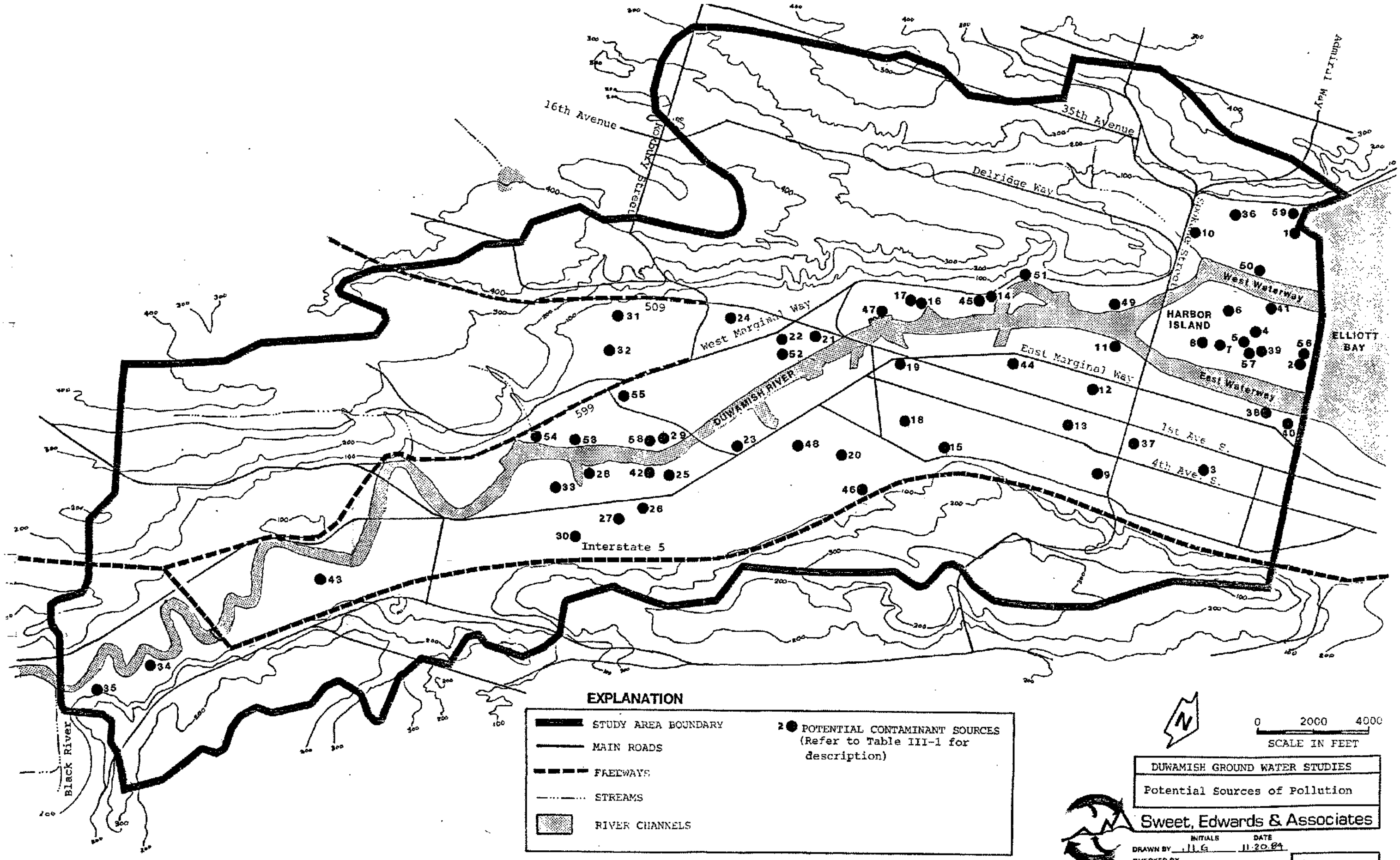

Base Map: U.S.G.S. 7½' Quad. Duwamish Head, Seattle South & Des Moines

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precipitation and contaminants infiltrating into the ground water system. For the purposes of this study, land use and how it relates to infiltration has been evaluated qualitatively. Areas are classified as predominantly industrial, residential, and as open space (farms, golf courses, undeveloped, etc.) from city and county land use maps and areal photography. Industrial areas are generally covered by buildings, roads, parking lots, and other impervious surfaces which minimize infiltration of precipitation. These same areas contain multiple land disposal sites with potential for ground water contamination. Residential areas have a lower percentage of area with impervious surfaces and fewer potential contaminant sources. An exception is Allentown, which is on septic tanks and drainfields with a high potential for nitrate contamination. Open space areas have a high infiltration potential and a low to moderate pollution potential.

Beginning in the late 1800's, extensive topographic modifications were made, particularly in the northern half of the basin. The river was straightened and the wetland part of the estuary almost completely filled about the time Harbor Island was created. Primary filling was completed by about 1918 (see Appendix D for details). Fill was acquired from a variety of sources, but primarily dredge spoils were used. Some industrial and domestic wastes were dumped in the fill areas. At least three designated refuse dumps also existed. Current and past industry includes manufacturing, warehousing, metals smelting and fabrication, cement production, bulk fuel storage, metal finishing, wood treating, chemical manufacture, chemical recycling, shipbuilding, docks, railroad and aircraft construction, with attendant transportation and utilities services.

Land use in the upland areas is primarily residential with attendant service facilities (retail, gas stations, etc.). The northern two-thirds of the valley floor is almost exclusively industry. Exceptions are Kellogg Island, a wildlife preserve, and a small residential area (South Park) on the west side of the river. The southern third of the valley floor is less developed and includes a few farms, a golf course, and Allentown. Figure III-3 - Potential Sources of Pollution shows the location of major industries which produce or handle toxic substances on sites (i.e., landfills) which are a potential source of pollution. These sites are listed in Table III-1. The use of specific industry names and sites is for the purpose of location reference and siting of future monitoring wells. Numerous other, unnamed smaller industries and companies such as gas stations, dry cleaners, etc., also handle toxic substances and are classes as potential pollution sources. Likewise, residential developments where fertilizers and pesticides are used are also considered potential sources of pollution. There is no indication and it is not implied that the companies, industries and sites listed are contaminating the ground water.

TABLE III-1 - POTENTIAL SOURCES OF POLLUTION*

Site Designation	Facility
1	Wyckoff Company
2	EPA Aerial Photo Analysis Site #18 (1961, liquid disposal area)
3	EPA Aerial Photo Analysis Site #2 (1940, general dump)
4	Seafab Metal Corporation (formerly RSR Quemetco)
5	Golden Penn Oil Company
6	EPA Aerial Photo Analysis Site #1 (1940, white waste mounds)
7	Seattle Iron & Metal
8	Value Plating and Metal Polishing
9a,b & c	EPA Aerial Photo Analysis Sites #3, 4 & 5 (1940, general dumps)
10	Bethlehem Steel Company
11	Lone Star Cement Company, Ash Grove Plant
12	EPA Aerial Photo Analysis Site #19 (1961, white waste mounds)
13a	Seattle City Light Substation
13b	Seattle City Light Georgetown Steam Plant
14	Ideal Basic Industries
15	Chemical Processors Inc-Georgetown facility
16	MST Chemicals
17	Kaiser Cement (transhipment area) (previously Reichold Chemical Corp.)
18	EPA Aerial Photo Analysis Site #7 (1940, waste pit)
19	EPA Aerial Photo Analysis Site #6 (1940, small dump areas)
20	EPA Aerial Photo Analysis Site #8 (1940, small industrial dump)
21	Northwest Cooperage Company
22	Liquid Air Company
23	AirCo.
24	South Park Landfill
25	Jorgensen Steel

TABLE III-1, CONTINUED

Site Designation	Facility
26	EPA Aerial Photo Analysis Site #12 (1940, white stockpile)
27	Kenworth Truck Company
28	Monsanto Company
29	A and B Barrel Company
30	EPA Aerial Photo Analysis Site #14 (1940, petroleum distributor)
31	Ace Galvanizing
32	Advance Electroplating
33	EPA Aerial Photo Analysis Site #13 (1940, uncontained storage tanks)
34	Seattle Rendering Works
35	Sunset Demolition
36	West Seattle Landfill
37	6th Avenue Landfill
38	Chevron USA
39	Texaco Refining and Marketing
40	GATX Tank Storage Terminals
41	Atlantic Richfield Oil Company
42	Isaacson Steel Company (site owned by Boeing)
43	Allentown (septic sewage systems)
44	Liquid Carbonic Corporation
45	Kaiser Cement and Gypsum Company
46	North Coast Chemical Company
47	Maralco Aluminum Incorporated
48	North Boeing Field
49	Terminal 105, Upland Dredge Spoil Disposal
50	Terminal 5
51	Kellog Island Upland Disposal Site
52	High Duty Alloy
53	Delta Marine Industries
54	Seattle City Light, Duwamish Substation
55	various plating works (area generally considered for RETS hazard evaluation)
56	Mobil Oil
57	Shell Oil
58	Malarky Asphalt
59	Purdy Recycling

* This listing is for location reference and the siting of monitoring wells. There is no indication and it is not intended to imply that any of the industries listed are contaminating the ground water.

Ground Water Extraction

The development or beneficial use of ground water must be considered in the design of any monitoring strategy.

While the purpose of this study is to focus on ground water contributions to the river, ground water pumping influences ground water flow and is often a source of drinking water supply. In addition, improperly sealed wells can serve as a conduit for contaminants to the ground water system. The number of wells in the valley is unknown. Undoubtedly, a large number of wells were constructed for water supply prior to service by the Seattle Water Department.

Of those drilled, only 27 supply wells are on record with the DOE and the USGS.[7,8] Most were drilled for industrial supply but have since been abandoned due to poor water quality. Inquiries to the Washington State Department of Social and Health Services, DOE and King County Department of Health Services indicate no present use of ground water in the study area. However, some wells may be in use in the southern part of the study area for single family dwellings or irrigation.

HYDROGEOLOGY

The hydrogeology of the study area is the single most important factor to consider in design of a monitoring strategy. The hydrogeology influences the direction, rate of movement, and concentrations of contaminants.

Geologic History

The Duwamish Valley is located in the central Puget Lowland physiographic province. The geology and physiography of the Puget Sound Lowland is the product of a number of complex geologic processes over a long period of time. Sylvester, 1971, has summarized these events in their order of occurrence.[9]

1. Submergence of the region under shallow seas from the Cambrian Period--600 million years ago (mya) to the early Mesozoic Era--200 mya.

2. Marine and continental vulcanism during the Mesozoic--225 to 65 mya.

3. Retreat of the seas as the continental land mass slowly rose during the late Mesozoic--150 to 65 mya.

4. Mountain building resulting from folding and faulting of the crust contemporaneous with vulcanism and lava flows in the early Tertiary Period--65 to 40 mya.

5. Uplift of the present Cascade and Olympic Mountains beginning in the Pliocene Epoch (7 mya) and continuing through the present.

6. Advances and retreats of the continental ice sheets during the Pleistocene Epoch--2.5 mya to 11,000 years ago.

7. Incision of valleys and the subsequent deposition of alluvial deposits in recent time--11,000 years ago to present.

The geology of the study area is primarily influenced by regional bedrock structure, glacial erosion and deposition, and fluvial deposition by the Duwamish River. Rogers, 1970, inferred from geophysical data a major structural feature trending east west through the study area [10] (see Figure III-4b - Geologic Map). South of this structural feature, bedrock is relatively close to the surface. North of the feature is a depression in the bedrock which has been filled with unconsolidated sediments. Hall and Othberg, 1974, estimated the thickness of the unconsolidated sediments to be about 3600 feet at the north end of Harbor Island to less than 300 feet just south of the island.[11]

Pliestocene glaciers advancing south from British Columbia eroded the valley bedrock creating a broad trough which was then filled as the glaciers retreated. A typical glacial sequence includes Advance Outwash (sand and gravel deposited in front of the advancing glacier), Till (highly compacted material which was overridden by the glacier), and Recessional Outwash (sand and gravel deposited on the till by the retreating glacier). Additionally, an advancing or retreating glacier will deposit thick sequences of silt and clay in proglacial lakes. Deposits of the last glaciation are called the Vashon Drift and within the study area include the Vashon Till, Esperance Sand (advance outwash) and the Lawton Clay (proglacial lake deposits). See Figure III-5 - Regional Cross Section A-A' for the vertical distribution of these units across the valley.

ARTIFICIAL FILL - modified land: areas leveled by cut and fill.

ALLUVIUM - chiefly sand and silt, some clay and peat. Includes areas of beach deposits and landslides.

VASHON TILL - compact mixture of silt, sand, gravel and clay.

ADVANCE OUTWASH - chiefly medium to coarse sand and pebble gravels.

LAWTON CLAY - mostly cohesive overconsolidated clayey silt.

SEDIMENTARY ROCKS - sandstones, siltstones, shales and conglomerates of Eocene and Oligocene age.

INTRUSIVE ROCKS - pyroxene andesite and basalt.

GEOLOGIC CONTACT - dashed where approximately located.

POSTULATED FAULT - showing realitive movement.
U = upthrown side; D = downthrown side.

A — A' Schematic Cross Section A-A' Location

DUWAMISH GROUND WATER STUDY

Geologic Map Legend

Sweet, Edwards & Associates

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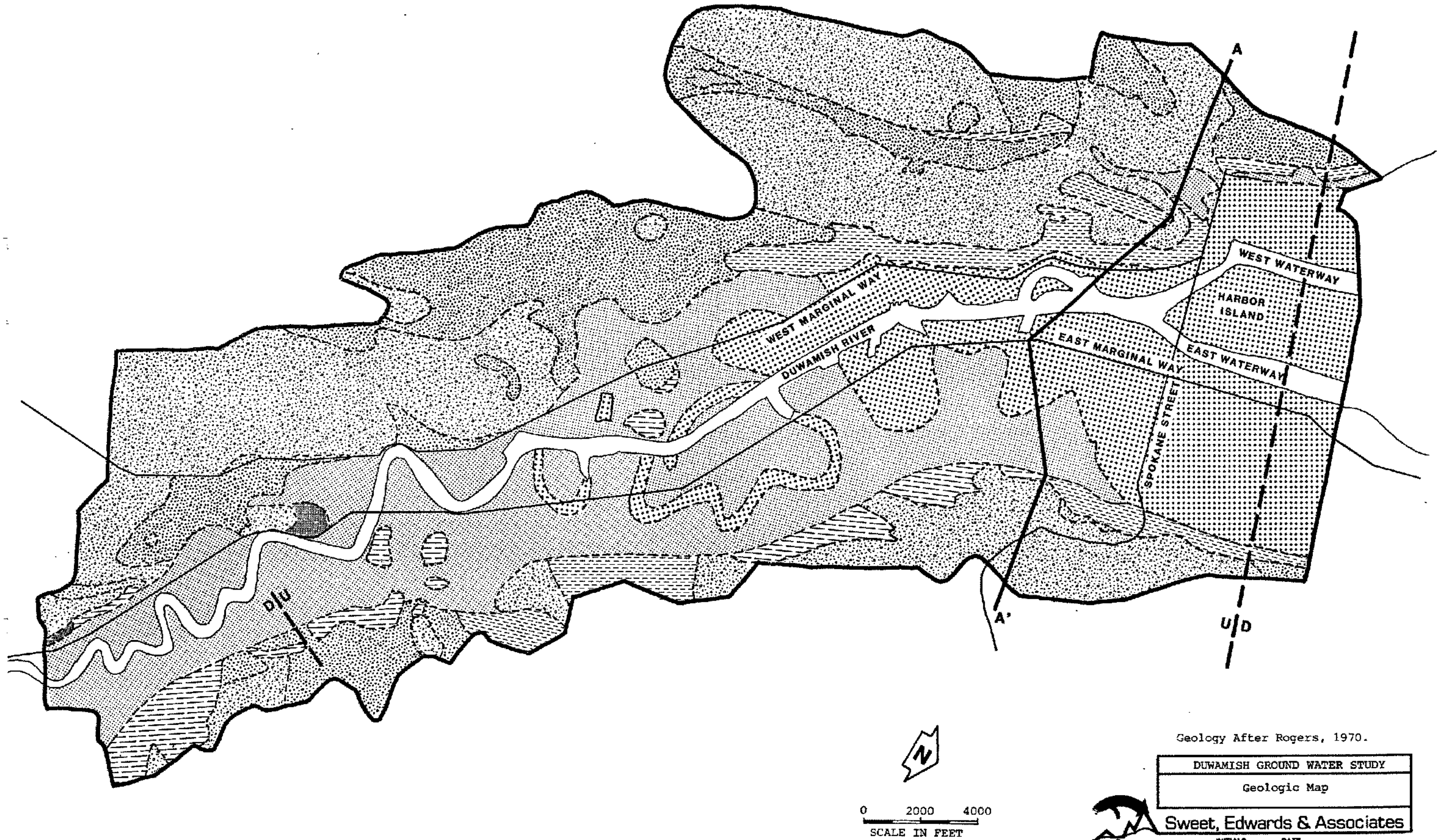
Figure III-4a



Geology After Rogers, 1970.

DUWAMISH GROUND WATER STUDY

Geologic Map

Sweet, Edwards & Associates

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REVISED

Figure III-4b

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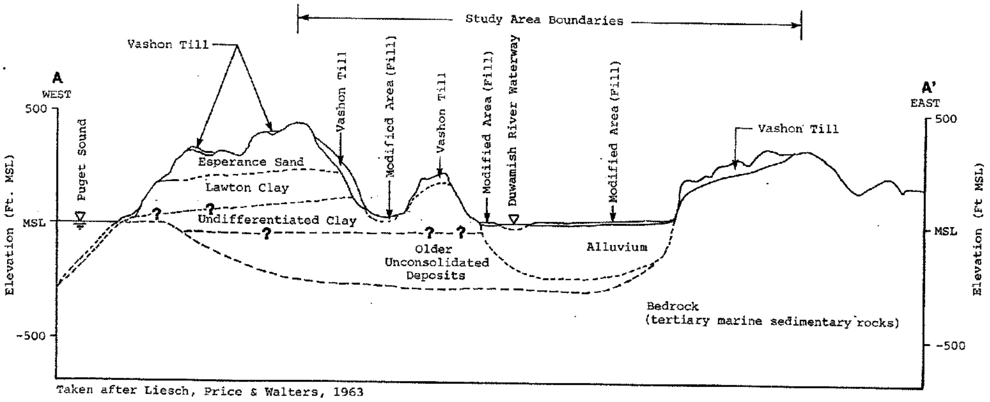

Taken after Liesch, Price & Walters, 1963

0 4000 8000
Horizontal Scale in Feet
Vertical Exaggeration x1.67

DUWAMISH GROUND WATER STUDIES

Schematic Regional Cross Section A-A'

Sweet, Edwards & Associates

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Figure III-5

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Of particular interest to this investigation are the alluvial sediments which make up the valley floor and were deposited since the last glaciation. The distribution of these materials are discussed in greater detail in Section IV - Valley Floor Characteristics.

Geologic Units

Eight major geologic units are present in the Duwamish Valley:

- Artificial Fill
- Alluvium
- Estuarine Deposits
- Vashon Till
- Esperance Sand
- Glacio Lacustrine Deposits
- Salmon Springs Drift
- Bedrock

Artificial Fill. Includes materials placed by man, primarily fine grained dredged sediments such as sand and silt plus localized demolition and industrial wastes. Character of fill generally changes laterally and vertically over short distances. Silty sand and silt is the most common material type. Hydraulic conductivity (permeability of the fill) varies dramatically over short distances and is generally greater than underlying or adjacent natural sediments. As a result, filled river channels may act as zones of preferential flow. The variable nature of the fill material reduces predictability of contaminant behavior, however, the commonly fine grained nature and organic content increases contaminant attenuation. Thickness of the fill ranges from less than 3 to 30 feet or more in channels.

Alluvium. Present throughout the valley floor of the study area. Composed of interfingered strata of sand, silt, clay, gravel, and peat. Thickness varies from a few feet in the south to several hundred in the north. Permeability is generally low but moderate for the coarser fractions. Local ground water flow patterns can be complex, but the predominance of fine grained sediments favors contaminant attenuation.

Estuarine Deposits. Vary in composition from clayey silt to sand and gravel. Coarser material is reported to exist in the northern part of the study area.[12] Shells are typical and thickness ranges from a few feet to about 90 feet. Deposits vary laterally and vertically, commonly grading finer with depth. Permeability is relatively low with relatively high attenuation potential except for coarser fractions.

Vashon Till. Compact, unsorted mixture of clay, silt, sand and gravel. Commonly called "hardpan." This occurs on upland slopes and beneath the alluvium. The till has very low permeability promoting runoff from upland slopes and may serve as a confining layer or barrier to the flow of ground water and contaminants. Tills covering the uplands are from the Vashon glaciation. Origin of tills beneath the valley floor is uncertain, but may be part of the older Salmon Springs Drift.

Esperance Sand. Brown, stratified sand with small lenses of clay silt and gravel. Represents advance outwash deposits of the Vashon glaciation. The Esperance Sand is well exposed in the ridge forming the western boundary of the study area. Permeability is moderate and potential attenuation of pollutants is low. However, the unit's stratigraphic position, well up on the ridge in a predominantly residential area, reduces the potential for contribution of contamination to the river from the Esperance Sand.

Glacio Lacustrine Deposits. Lake sediments underlying most of the western portion of the study area and composing the lower part of the western ridge. Covered by Vashon Till or Alluvium in most areas and underlain by till in the valley floor. The lake deposits consist primarily of silt, clayey-silt, and clay with some fine sand and gravel in the northern part of the study area. However, there is some sand and gravel in the southern part of the study area. These deposits include the Lawton clay, member of the Vashon Drift, but may also include some nonglacial silt and clay of the Kitsap Formation and lake deposits of the Salmon Springs Drift. Total Thickness of the lake deposits may be in excess of 300 feet.

Permeability is moderate to high with low pollutant adsorption in the coarse fraction. The fine grained fraction exhibits very low permeabilities with high contaminant and attenuation potential.

Salmon Springs Drift. Undifferentiated glacial drift including till, outwash sand and gravel, and glacio-lacustrine silt and clay. Outwash deposits are an important aquifer beneath west Seattle. Permeability and pollutant mobility is varied.

Bedrock. Forms the ridge on the southeast side of the valley. Bedrock outcrops in the southern third of the valley floor, but plunges to considerable depth under Harbor Island. Bedrock is primarily sandstone and siltstone with intrusions of andesite.

The sandstones and siltstones are typically hard and low to moderate in permeability, however, uncemented or weathered fractions are common. Considerable faulting and folding is evident with closely spaced fractures which increase the permeability.

The andesite is an impermeable crystalline rock, but also heavily fractured. The andesite is quarried at the nearby Black River Quarry. Quarrying operations tend to mobilize sulfurous minerals deposited in the fractures.[13]

Ground Water

Glacial geology dominates the uplands and fluvial geology dominates the valley floor. This variation in geologic character defines two different ground water regimes within the study area. Pollution potential is significantly different also, with the uplands primarily residential and the valley floor primarily industrial.

There is insufficient data to define the number of aquifers present or a potentiometric surface from which we can deduce the direction of ground water flow. Figure III-6 - Schematic Ground Water Flow Map illustrates the general direction of ground water flow based on the assumption of a potentiometric surface reflecting surface topography.

It is likely that at least two major components to ground water flow exist within the study area. A deeper component, predominantly in the deep glacial alluvial sediments with minimal influence from the river, and a shallow component which is heavily influenced, at least within the valley floor, by river levels and tidal activity.

Upland Ground Water Regime. The upland aquifers are composed of glacial and interglacial material on the west and northeast. To the east and southeast, ground water occurence is predominantly within the bedrock. There are no reported wells in the bedrock in the east. With the exception of limited flow through fractures, the bedrock probably serves as a ground water barrier. North of the structural feature, beneath Beacon Hill (see Figure III-4 - Geologic Map), ground water in the uplands

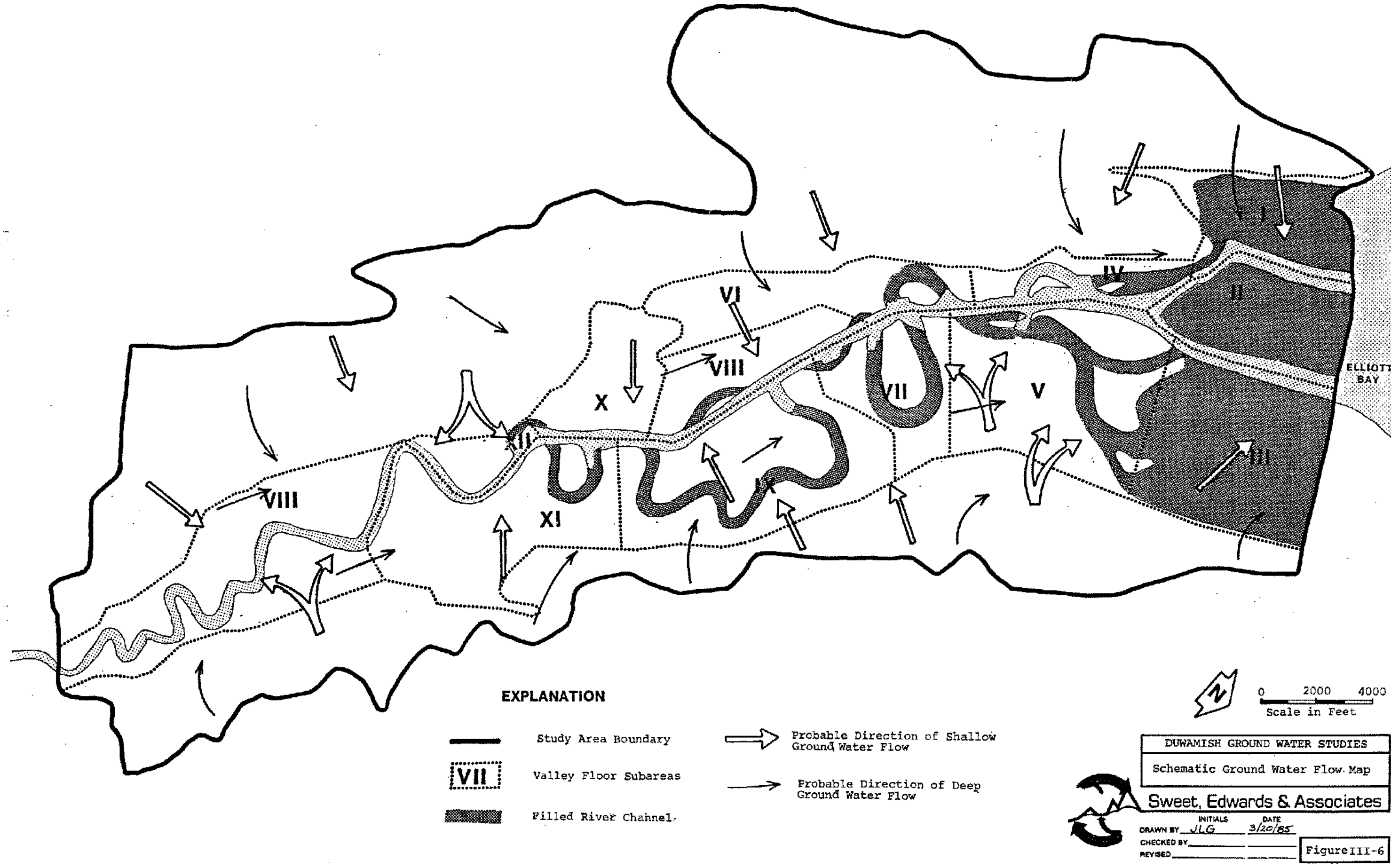
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
ELLIOTT BAY
EXPLANATION
Study Area Boundary
VII
Valley Floor Subareas
Filled River Channel
Probable Direction of Shallow Ground Water Flow
Probable Direction of Deep Ground Water Flow
N
0 2000 4000
Scale in Feet
DUWAMISH GROUND WATER STUDIES
Schematic Ground Water Flow Map
Sweet, Edwards & Associates
DRAWN BY JLG 3/20/85
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Figure III-6

occurs primarily in pre-Vashon sand and gravel (Salmon Springs Drift) which is mantled by Vashon till.

The west upland is topographically higher than the east and the ground water geology is a little better defined due to data derived from the METRO Tunnel Study.[14,15] As in the northeast, the major aquifers are the Esperance Sand and the Salmon Springs Drift (Olympia gravels) deposits. The Lawton Clay serves as a perching layer for ground water above.

Recharge to the upland aquifers is from precipitation infiltrating through the till mantle. Discharge is probably to the valley floor, however, hydraulic connection with the valley floor is not defined. Subsurface flow from the upland aquifers to the valley floor aquifers is probably greater along the south or central part of the west uplands than elsewhere in the study area.

The ground water quality of the uplands is relatively good. The potential for pollution is relatively low due to the lack of industry and the use of sewers.

<u>Valley Floor Ground Water Regime</u>. The ground water of the valley floor is the primary focus of this project due to the high potential for contamination from industry and the proximity of the river. There are few major aquifers which would provide significant yields to wells. Most wells drilled in the area generally tapped small, isolated pockets of sand and gravel and were subsequently abandoned due to poor water quality. However, thick sand and gravel aquifers occur at depth.

The water bearing sediments of the valley floor alluvium are generally fine grained materials (fine sand and silty sand) with low to moderate permeabilities. Ground water gradients and velocity are also low based on limited studies at industrial sites. In localized areas, sand and gravel strata occur with higher permeabilities, but thick sections of silt and clay are more common.

The water table in alluvial basins commonly reflects topography with consequent ground water flow toward rivers and strongly affected by tidal influence in areas adjacent to estuaries. Where fill has been placed, preferential flow occurs due to the more permeable nature of the fill relative to similar naturally occurring sediments.

The effects of the river's salt wedge are a concern with respect to monitoring. Very little is known about solute transport in saline or brackish ground water, particularly with respect to inorganic contaminants. Studies on the reaction of metals in sea water indicates precipitation of some elemental contaminants with increases in salinity. Organic material in the Duwamish appeared to catalyze the reaction, lowering the salinity threshold.[16,17] As a result, selected contaminants may tend to precipitate out of the water column. On the other hand other contaminants, such as cadmium, may be mobilized in the organic rich brackish waters. A similar type of reaction would be expected in the brackish ground water of the valley floor. However, the extent of this similarity is uncertain due to the differing hydrochemistry of the ground water.

The ground water of the valley floor is discussed in more detail in the following section.

SECTION IV
VALLEY FLOOR CHARACTERISTICS

Based on the available hydrogeologic data, land use data, and evaluation of potential pollutant sources, the Duwamish Valley Floor should be the major focus of the monitoring strategy. Throughout most of the valley floor, shallow ground water discharges directly to the river. Large areas of fill and filled channels in the northern two-thirds of the valley floor promote preferential flow of ground water. The southern third of the valley floor is characterized by a thin mantle of sediment and bedrock outcrops.

The valley floor covers approximately 12 square miles and has been divided into 13 subareas to be considered individually with respect to:

- o Potential sources of pollution
- o Geology
- o Ground water
- o pollutant mobility

(See Figure IV-1 - Valley Floor Subareas)

Basis for Subdivision

Hydrogeologic data are insufficient to divide the valley floor accurately into hydrologic sub-basins. Therefore, the sub-basin boundaries were chosen using the following factors:

1. Present surface drainage
2. Historical drainage (prior to urbanization)
3. Possible ground water divides
4. Land use (pollution potential)
5. Size
6. Geology

General Assumptions

General assumptions have been employed dividing the valley floor into subareas and in our analysis with respect to monitoring.

1. Filled river channels are conduits of preferential flow.

2. Sewers, storm drains and underground pipe emplacements also serve as conduits of preferential flow, but due to their density and the lack of detailed knowledge of industrial piping whereabouts, underground structures are treated as a nonpoint source.

3. Ground water divides conform to surface water divides.

4. Shallow ground water flow is toward the river.

5. Storm drains and sewers follow topography and leakage does not influence direction of ground water flow.

6. Highly industrialized areas have a higher pollution potential than less developed areas.

7. Subsurface flow to valley aquifers from uplands is uniform throughout study area.

8. The Duwamish River is a hydrologic boundary to ground water flow.

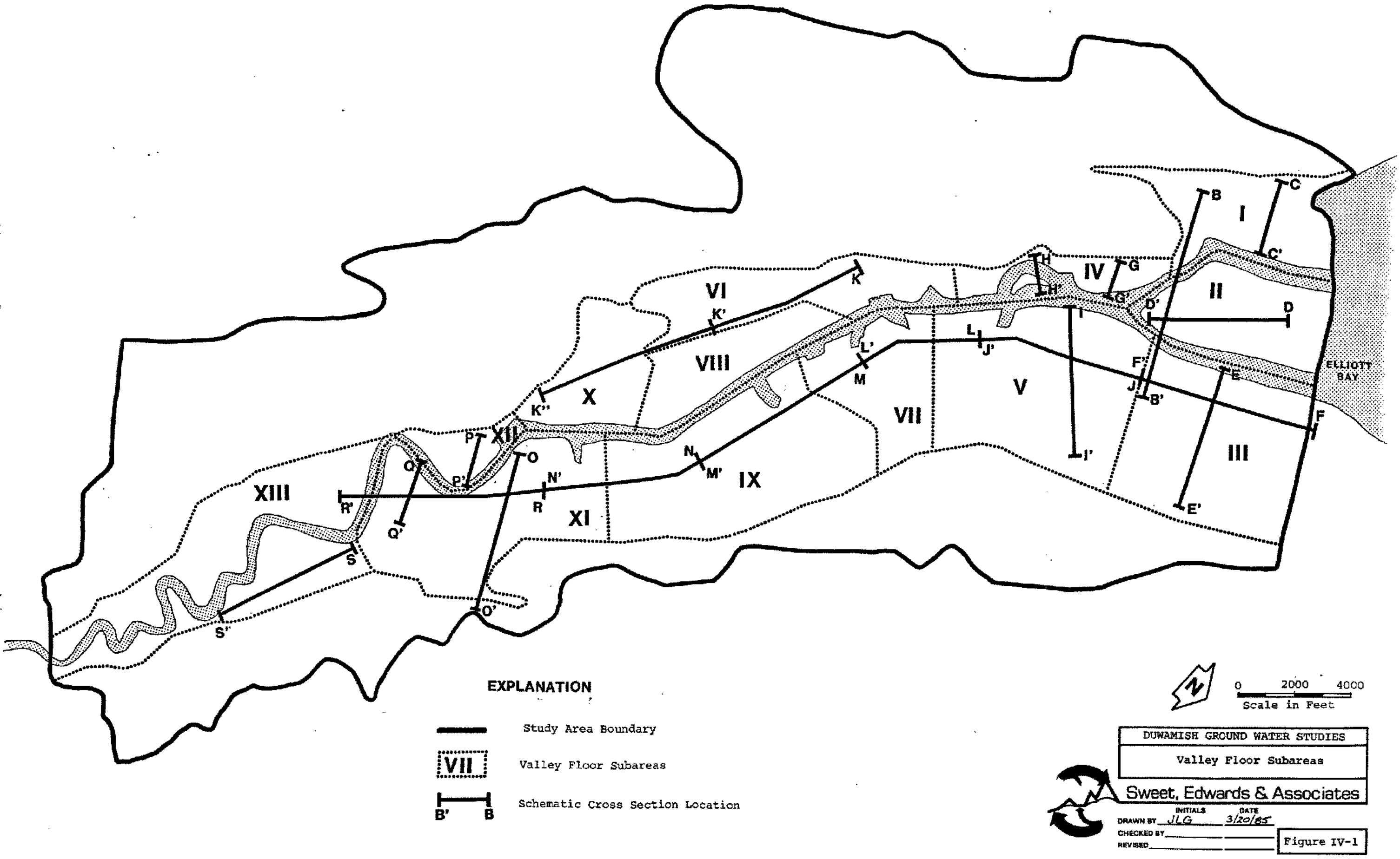
9. Fine grained and organic rich sediments have the highest attenuative capacity for ground water contaminants. Clean gravels and sands have the lowest capacity.

10. Where the sub-basins are bounded by the estuary, significant attenuation of dissolved contaminants may occur at the subsurface saline/fresh water interface.

<u>Subarea I</u>

This three-quarter square mile subarea is bounded on the north by Elliot Bay, on the west by the valley wall along Harbor Avenue S.W., the West Waterway on the east, and extends south to the lower reaches of Longfellow Creek. Longfellow Creek currently discharges to the west waterway at S.W. Hinds Street. The old channel is used as a discharge conduit for contact cooling water from Seattle Steel.

<u>Potential Sources of Pollution</u>. This subarea is primarily industrial with large paved areas along the docks. Infiltration potential is low except on the west. Potential sources include: Wyckoff, West Seattle Landfill (inactive), Terminal 5, and Bethlehem Steel. Possible contaminants include: wood preservatives, PCB's, cyanide metals, methane, solvents, Base-



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Geology. Fill thickens from the south to more than 25 feet in the north and may be thicker in the filled channels. For most of this subarea, the fill is predominantly silty sand to the west and sand to the east. Along the southern border, the fill is unclassified (see Figures IV-2 - Cross-Section B-B' and Figure IV-3 - Cross-Section C-C' & D-D'). Below the fill is silty sand underlain by generally clean, brown to black, fine to medium sand. To the south, the fill was placed on silt and gravel. Till ranges from about 40 feet to 130 feet deep.

Ground Water. Water levels generally reflect sea or river levels with flow in the north probably to the West Waterway and Elliott Bay, and to Longfellow Creek or the West Waterway in the south. Tidal influence is strong, probably reversing flow directions near the bay and the waterway.

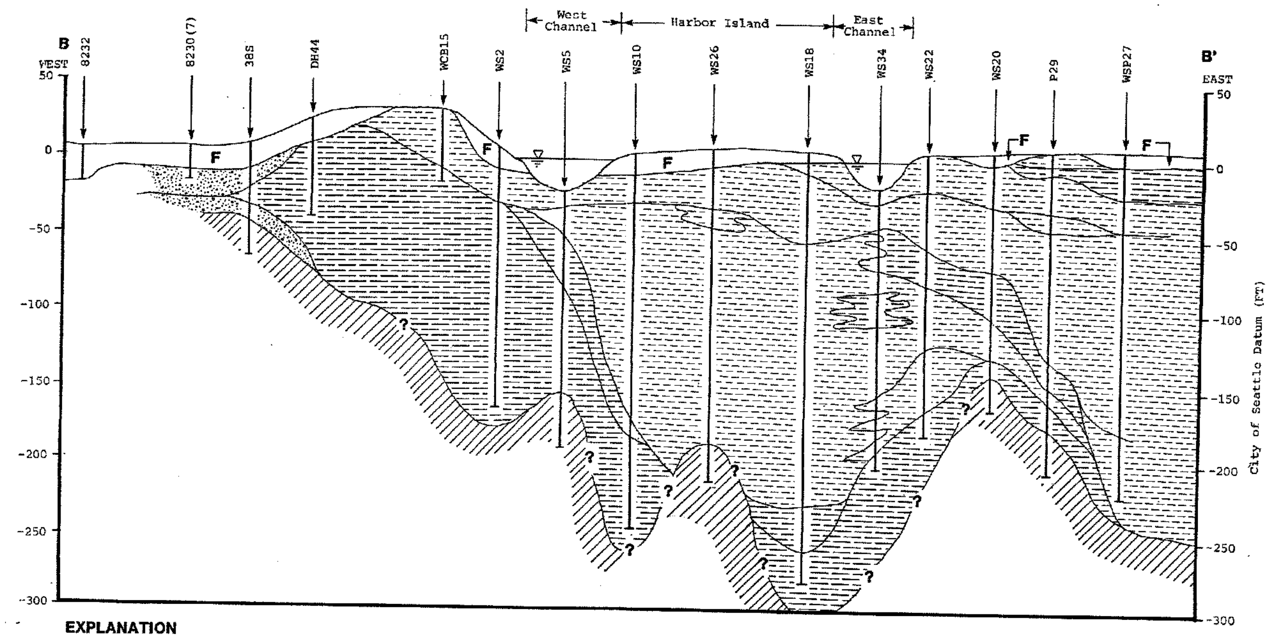
Subarea II

This subarea consists of Harbor Island. It is surrounded by the west and east Waterways and Elliot Bay, all saline or brackish waters. The island covers about eight-tenths of a square mile and is traversed northeast by a relatively indistinct buried channel in the southern part of the island.

Potential Sources of Pollution. The island is exclusively industrial with a high percentage of paved area. Infiltration potential is moderate to low and storm drains are relatively short and straight to the river. Major potential contaminant sources include: SeaFab Lead Smelter, Seattle Iron and Metal, Value Plating and Metal Polishing, several bulk petroleum distributors, shipyards, and other sites identified by the EPA areal photo survey. Potential contaminants include: heavy metals, cyanide, petroleum products, and solvents.

Geology. The entire island is composed of sandy fill to depths of 30 feet (see Figure IV-3 - Cross-Section C-C' & D-D'). Very little subsurface information is available for the west side of the island. Test borings indicate an undulating, irregular pre-fill surface. Below the fill, is about 80 to 150 feet of silty sand, sandy silt, and silt underlain by clean sand, with till at depths of 170 to 300 feet.

Ground Water. Flow is expected to be toward the nearest margin of the island. Ground water levels probably reflect tidal fluctuations near the island margins. Hydraulic continuity



EXPLANATION

F Unclassified Fill

Gravel, Sand & Gravel

Silty Sand, Sandy Silt, Sand & Silt

Clay & Silt

Glacial Till

WS10 Test Hole

Depositional Contacts

0 600 1200
Scale in Feet
Vertical Exaggeration x10

DUWAMISH GROUND WATER STUDIES

Schematic Cross Section B-B'

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Figure IV-2

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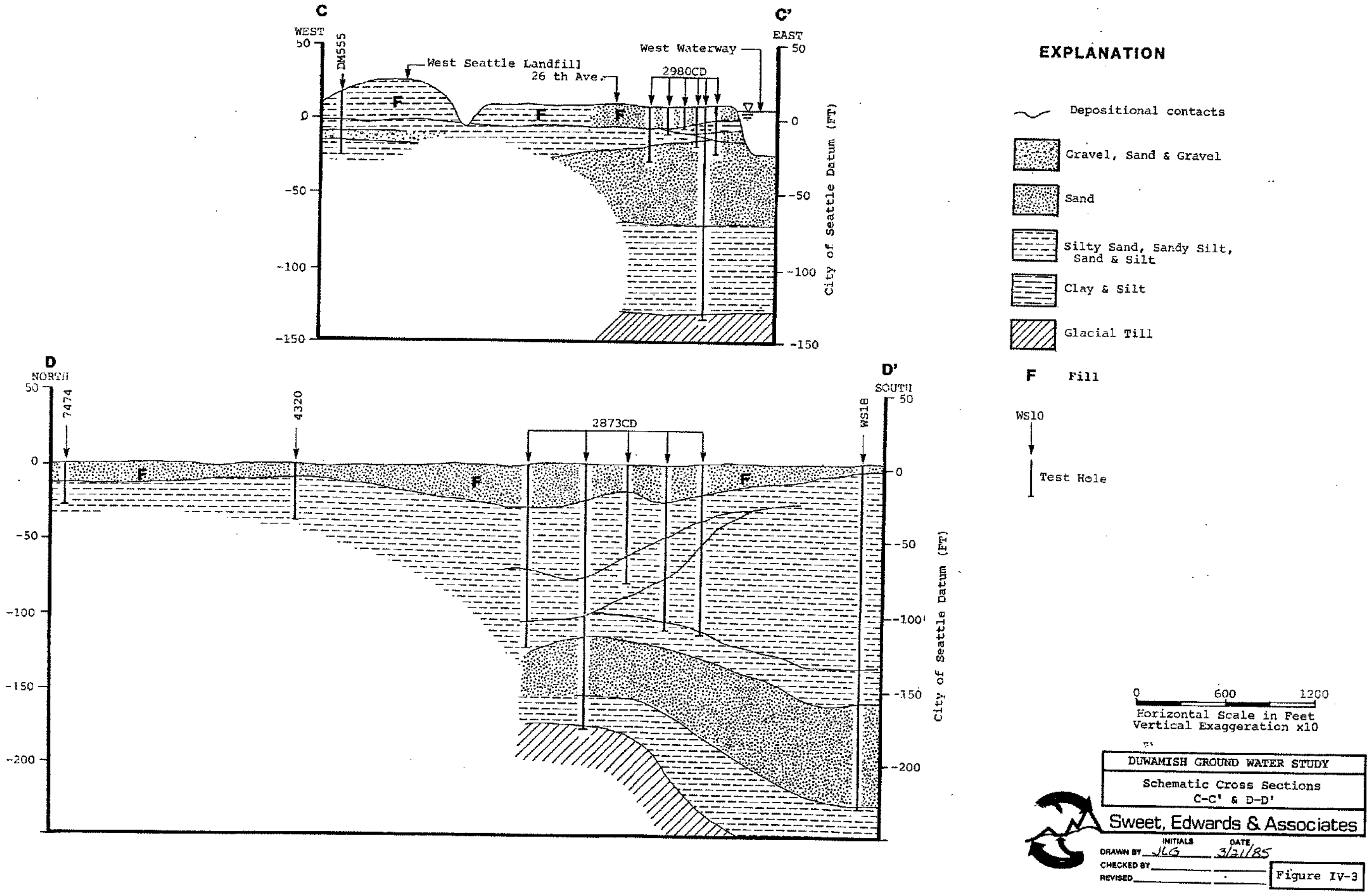

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between the fill and river is high except where sheet piles and compacted berms have been constructed.

Subarea III

This subarea covers about one and a third square miles and is bounded on the north by Atlantic Street, on the west by the East Waterway, on the south by Spokane Street, and on the east by Interstate 5. This area was previously a tide flat with tall grasses on the east. It is likely that at least the eastern portion of this area was covered with mud prior to filling, but tidal action washed out the fines on the west, leaving a sandy bottom.

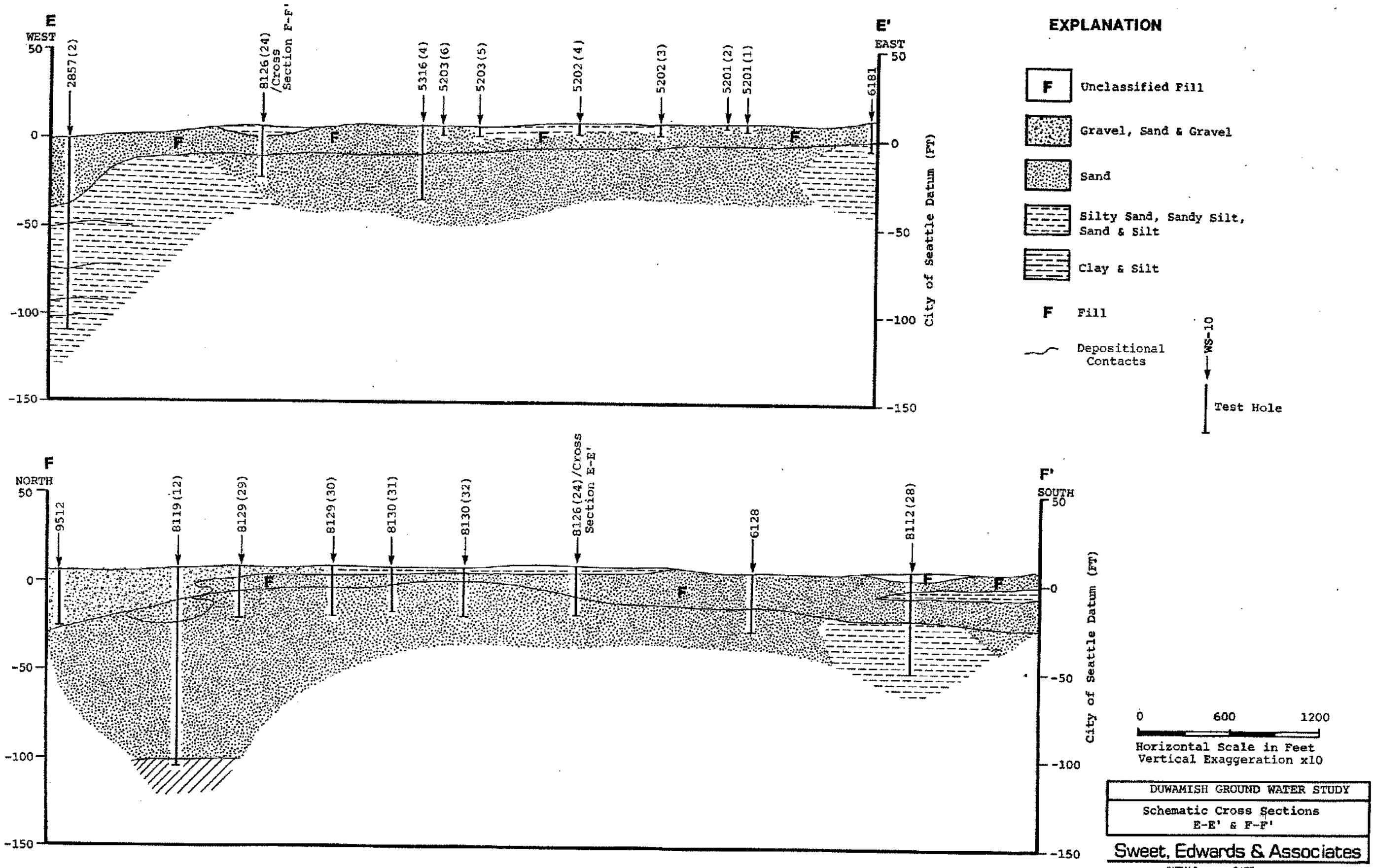
Potential Sources of Pollution. Most of this subarea is industrial and paved except for extensive rail development. Infiltration is moderate to low. Potential sources of pollutants include: 6th Avenue Landfill, numerous undesignated landfills, two bulk petroleum distributors, railroads, and various manufacturing plants. Potential pollutants include: petroleum products, wood preservatives, solvents, heavy metals and methane gas.

Geology. The entire subarea has been filled, with fill thickness ranging from 12 feet on the east to more than 48 feet on the west (see Figure IV-4 - Cross-Sections E-E' and F-F'). The fill varies in composition including gravel, sand, silty sand, clay and refuse. The fill is underlain by silt to the east and sand and silty sand to the west. Till was reported in one boring at a depth of 120 feet.

Ground Water. Flow is probably west to the East Waterway. Tidal influences, with resultant varying ground water flow direction, may be significant in the western part of the subarea.

Subarea IV

This subarea covers about one quarter square mile and is bounded on the north by Spokane Street and on the east by the Duwamish River. The south boundary is just south of Brandon Street SW, and the slope to the uplands forms the west boundary. This subarea includes Kellogg Island and a buried creek and river channel in the northern part of the subarea.



DUWAMISH GROUND WATER STUDY

Schematic Cross Sections
E-E' & F-F'

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Figure IV-4

Potential Sources of Pollution. Kellogg Island and an old river bend are in the center of the subarea and have been preserved as a wildlife reserve. This area has a relatively high infiltration potential. The remainder of the subarea is industrial and paved, with a low to moderate infiltration potential. The major potential sources of pollution include: Ideal Basic Industries, Kaiser Cement and Gypsum Company, Terminal 105, and the Kellogg Island Upland Disposal Site. Principal identified contaminants may include flue dust, kiln and truck washdown water, and leaching from contaminated dredge spoils.

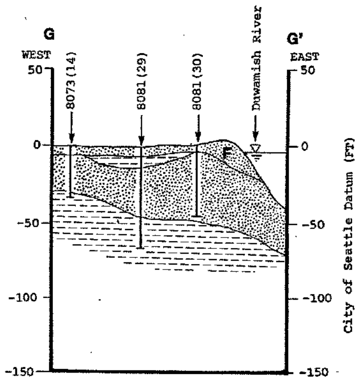
Geology. About 6 feet of mixed fill covers the developed area (see Figure IV-5 - Cross-Sections G-G' & H-H'). It is thicker in the north and buried channels. The fill consists of predominantly silty sand, but silt and gravel pockets are common. Below the fill is 20 feet or more of coarse, black sand with a relatively thick (5-10 feet) peat layer in the upper part. The peat is primarily in the central part of the subarea and under Kellogg Island. Below the sand is a thick layer of silt with interbeds of sand.

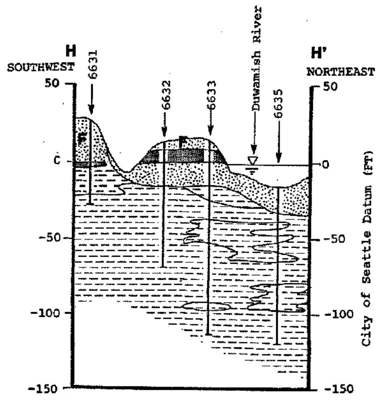
Ground Water. Flow is toward the river in the south with a minor diversion to the north in the filled creek bed. North of Kellogg Island, easterly flow may be diverted north by the filled river channel. Most ground water is expected to perch on the silt and flow toward the river. Recharge from upland aquifers is reduced by clay slopes and thinning of the sand layer to the west.

Subarea V

This subarea covers about one and a half square miles and is bounded on the north by Spokane Street, on the west by the Duwamish River, and on the east by Interstate 5. The southern boundary runs east-west between Orcas and Fidalgo Streets South. The north and western parts of the subarea includes filled distributary channels. The eastern and southern parts of the subarea are reported to have been wooded prior to development.

Potential Sources of Pollution. Most of this area is industrial with a large rail facility. Infiltration is moderate to low. Potential sources include: Ash Grove Cement, Seattle City Light Substation, ChemPro, Liquid Carbonic Corporation, several refuse dumps, mounds and waste pits. Major contaminants suspected include: PCB's, solvents, methane gas, and heavy metals.





EXPLANATION

- F — Unclassified Fill
- Sand
- Silty Sand, Sandy Silt, Sand & Silt
- Clay & Silt
- Peat
- F — Fill
- WS-10 — Test Hole
- Depositional Contacts

0 600 1200
Horizontal Scale in Feet
Vertical Exaggeration x10

DUWAMISH GROUND WATER STUDY

Schematic Cross Sections
G-G' & H-H'

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Figure IV-5

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Geology. Typically, there is 10-20 feet of fill throughout most of the area, predominantly silt and silty sand (see Figure IV-6 - Cross-Sections I-I' & J-J'). Below the fill is fine to medium sand with silt lenses. Clay is present at a depth of 55 feet on the east dropping to 250 feet on the west.

Ground Water. Flow is complicated by filled channels in the north diverting ground water to subarea III. Channel on the west side of subarea is filled with sand, so a westward flow toward the river is probable.

Subarea VI

This subarea covers approximately three quarters of a mile and is bounded on the north by Orcas Street SW, on the west by the valley slope, on the east by First Avenue South, West Marginal Way, and the Duwamish River on the south. The area is bounded by a drainage divide at approximately Henderson Street South. West Marginal Way acts as a drainage divide and a north flowing stream enters a filled river bend.

Potential Sources of Pollution. The northern part of this subarea is almost completely paved. The remainder is primarily industrial except for some residential use at the southern end. Infiltration is low in the north and low to moderate in the rest of the area. Pollution sources include: MRI, Reichold Chemical, South Park Landfill, and Maralco Aluminum Inc. Potential Contaminants include: heavy metals, acids, solvents, and other organics.

Geology. Fill consists of mostly sand and silt and covers most of the subarea (see Figure IV-7 - Cross-Section K-K'-K"). Materials beneath the fill are predominantly sand with layers of silt and silty sand. Silt is more prevalent in the north while sand is more prevalent in the south. A shallow ridge of glacial sand and gravel is buried beneath the south end of the subarea.

Ground Water. Flow is to the north, then to the river. The small north-flowing stream may be a discharge point for ground water. Ground water flow may also be to the east toward the river in the south.

Subarea VII

This subarea covers approximately two-thirds of a square mile with its northern boundary between Fidalgo and Findley Streets South. The river serves as the west boundary and Interstate 5 as the east boundary. The southern boundary is near the intersection of Ellis Street and East Marginal Way. This subarea was developed on a large filled meander.

Potential Sources of Pollution. This subarea is predominantly industrial with a band of dense residential usage along the east side. Infiltration potential is moderate to low. Known potential sources include a waste pit and two small dumps.

Geology. Most of this area is covered with about 5 to 10 feet of fill (predominantly sand and silty sand) except in the old river meander where the fill is up to 35 feet thick (see Figure IV-8 - Cross Section L-L' & M-M'). Below the fill is approximately 60 feet of natural sand and silty sand with occasional silt interbeds.

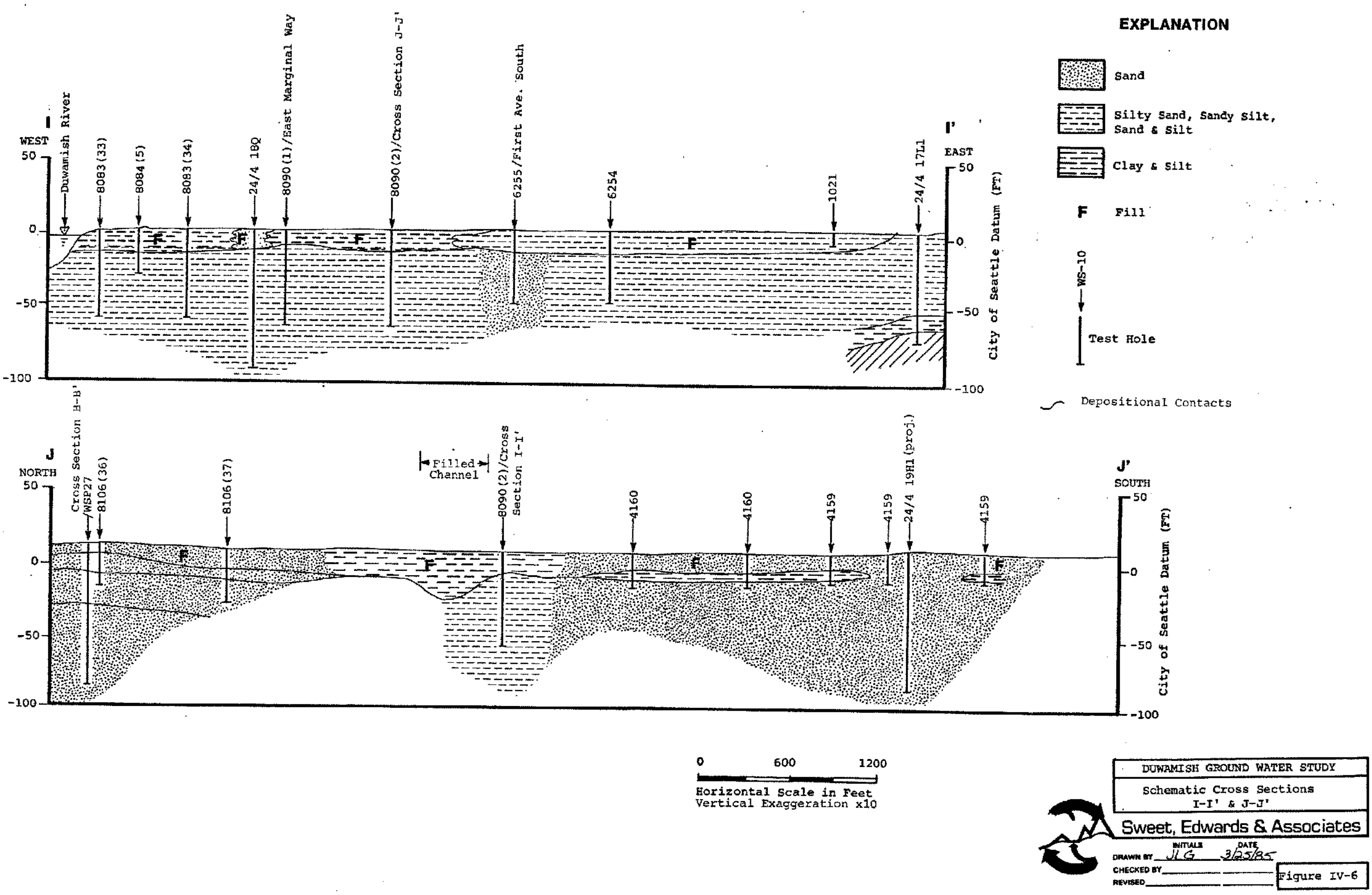
Ground Water. Flow is probably influenced by the filled channel which diverts flow to the river.

Subarea VIII

This subarea covers about one and two-thirds square miles and is bounded on the north by First Avenue South. The west boundary is West Marginal Way. The east is bounded by the river and Henderson Street South is the southern boundary. A filled oxbow underlies this subarea both ends of which are on the Duwamish River.

Potential Sources of Pollution. Heavy industry covers the northern two-thirds of the area and infiltration potential is low, while residential land use covers the southern third and infiltration potential is moderate to high. Potential sources include Malarky Asphalt, Northwest Cooperage Co., Liquid Air Co., High Duty Alloy and various plating works. Potential contaminants are expected to be predominantly metals and solvents.

Geology. Most of the area is covered with about 5 to 15 feet of fill, mostly sand and silty sand with thin layers of silt (see Figure IV-7 - Cross Section K-K'-K"). The fill is underlain in parts by silt and clay which appears to have been



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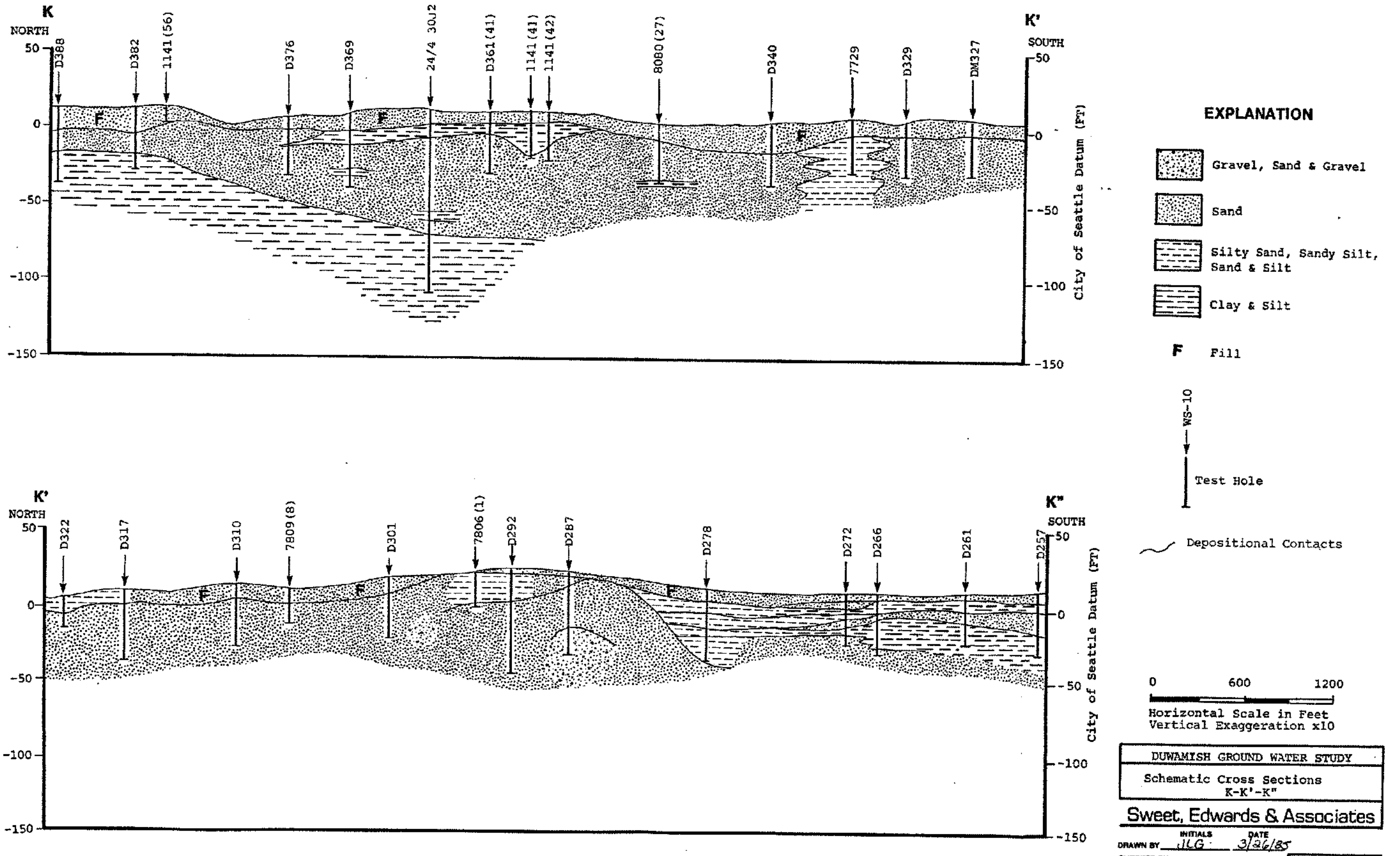

DUWAMISH GROUND WATER STUDY

Schematic Cross Sections
K-K'-K"

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Figure IV-7

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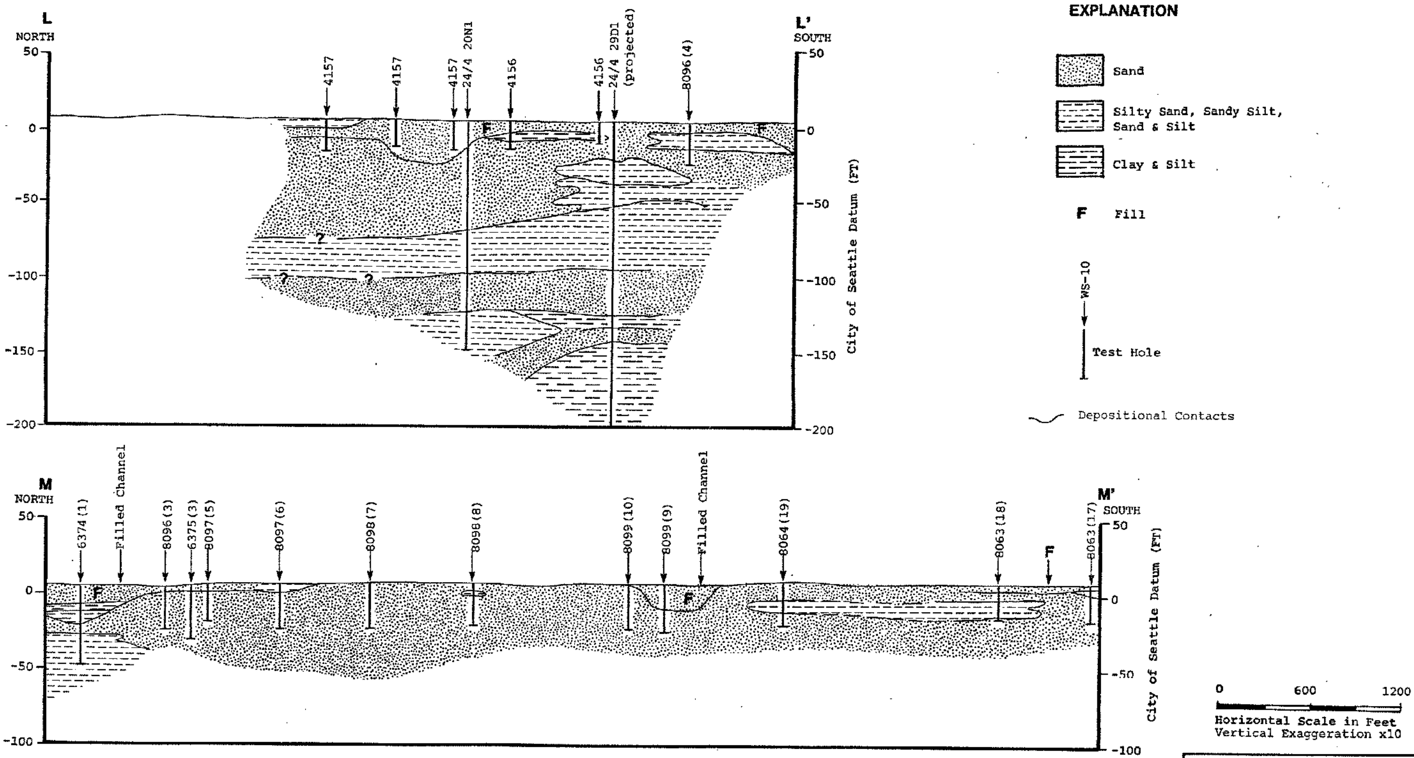

DUWAMISH GROUND WATER STUDY

Schematic Cross Sections
L-L' & M-M'

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Figure IV-8

CARG007048

SEA140969

deposited in old river channels. Some sand and peat occurs in these features. A fine to coarse black sand underlies most of the area beneath the fill and clay. A sandy-silty glacial lacustrine deposit occurs at a depth of about 65 feet and sedimentary bedrock outcrops on the southern boundary.

Ground Water. Flow is east to the river and may be locally altered by the oxbow. Seeps have been observed in the river bank at low tide (personal communication, Tom Hubbard). Some subsurface flow to subarea IV is likely in the northwest via the filled channel.

Subarea IX

This subarea covers about one and a half square miles, most of which includes Boeing Field. The western boundary is the Duwamish River and the northern boundary is near Ellis Street South. Interstate 5 forms the east boundary and the southern boundary is near Henderson Street South. A long buried meander channel crosses much of the area and is linked to the river.

Potential Sources of Pollution. This subarea is exclusively industrial with much of the area covered by concrete. Infiltration potential is low. Potential sources include: Air Co., Jorgenson Steel, Kenworth Truck Co., Isaacson Steel, North Coast Chemical Co., Boeing, the Georgetown Steam Plant and several unidentified EPA photo sites. Potential contaminants include: heavy metals, solvents, and PCBs.

Geology. Sandy fill is common to about 30 feet in the west part of the subarea where the old channel was filled. Most of the rest of the area is underlain by a thin fill (<5 feet) which in turn is underlain by a thick deposit of sand (see Figure IV-8 - Cross Section L-L' & M-M'). Thin strata of silty sand and sandy silt are present in the north and south parts of the area.

Ground Water. Flow is expected to be greatly influenced by the buried channel. Most ground water probably flows to the channel and then along it to the river. Studies at the Georgetown Steam Plant support this pattern. Flow west of East Marginal Way is probably directly toward the river.

Subarea X

This subarea covers about one half square square mile. It is bounded on the north by a drainage divide near Henderson Street South and the river on the east. The valley slope forms the boundary on the south and west. The middle of this area was a wetland prior to development.

Potential Sources of Pollution. This subarea is covered with industry except for a small residential area in the north. Infiltration potential is low except for the north, west and possibly southern margins where it is moderate. Potential sources include: A&B Barrel Company, Ace Galvanizing, Advance Electroplating, Delta Marine Industries, Seattle City Light Duwamish Substation and various other plating works. Potential contaminants include heavy metals, oils, grease, sodium hydroxide, PCBs and solvents.

Geology. Fill is generally less than 5 feet thick except in areas where wetland depressions or streams had existed. In these areas it is as much as 10 to 20 feet thick. Below the fill are interbeds of alluvial and estuarine sand, silt and clay (see Figure IV-7 -Cross Section K-K'-K"). Very dense glacial sand, silt and gravel underlie the northern and western parts of the area with bedrock as shallow as 45 feet.

Ground Water. Flow is generally toward the central and east part of the subarea following the topography. High recharge and underflow rates are expected from the underlying and surrounding coarse glacial deposits.

Subarea XI

This subarea covers about one square mile with the northern boundary near Henderson Street South and the southern boundary near 116th Street South. The west boundary is the river and the east boundary is Interstate 5. A filled meander is beneath the northern part of the area and a tributary valley enters on the east side. A bedrock ridge separates the southern third of the area.

Potential Sources of Pollution. This subarea is primarily industrial with some agricultural and residential usage in the southeast. Boeing dominates the northern part of the area and the east central part is undeveloped. Low infiltration potential is expected in the west and north with moderate to high infiltration potential in the east and south. Potential sources include: Boeing and a previous petroleum distributor. Potential contaminants include petroleum products, fertilizers, pesticides and solvents.

Geology. The fill is sandy and is generally less than 5 feet thick except in the buried channel where it is more than 25 feet deep. Below the fill is sand with numerous clay, silt and silty sand lenses (see Figure IV-9 - Cross Sections N-N' and O-O'). A 15-30 foot thick clay/silt deposit occurs from depths of 15 to 60 feet in the north central part of the subarea. Sedimentary bedrock occurs in the southern and eastern part of the area and is present at shallow depths under the alluvium.

Ground Water. Flow is very complex in this subarea. In the north flow is probably diverted west by the filled channel. The bedrock highs may divert flow toward the river. The tributary valley entering on the east along with high rates of runoff from the bedrock slopes of the valley wall increases recharge to the subsurface.

Subarea XII

This subarea covers a quarter square mile and is bounded on the north, east and south by the river. The west boundary is the slope of the valley wall.

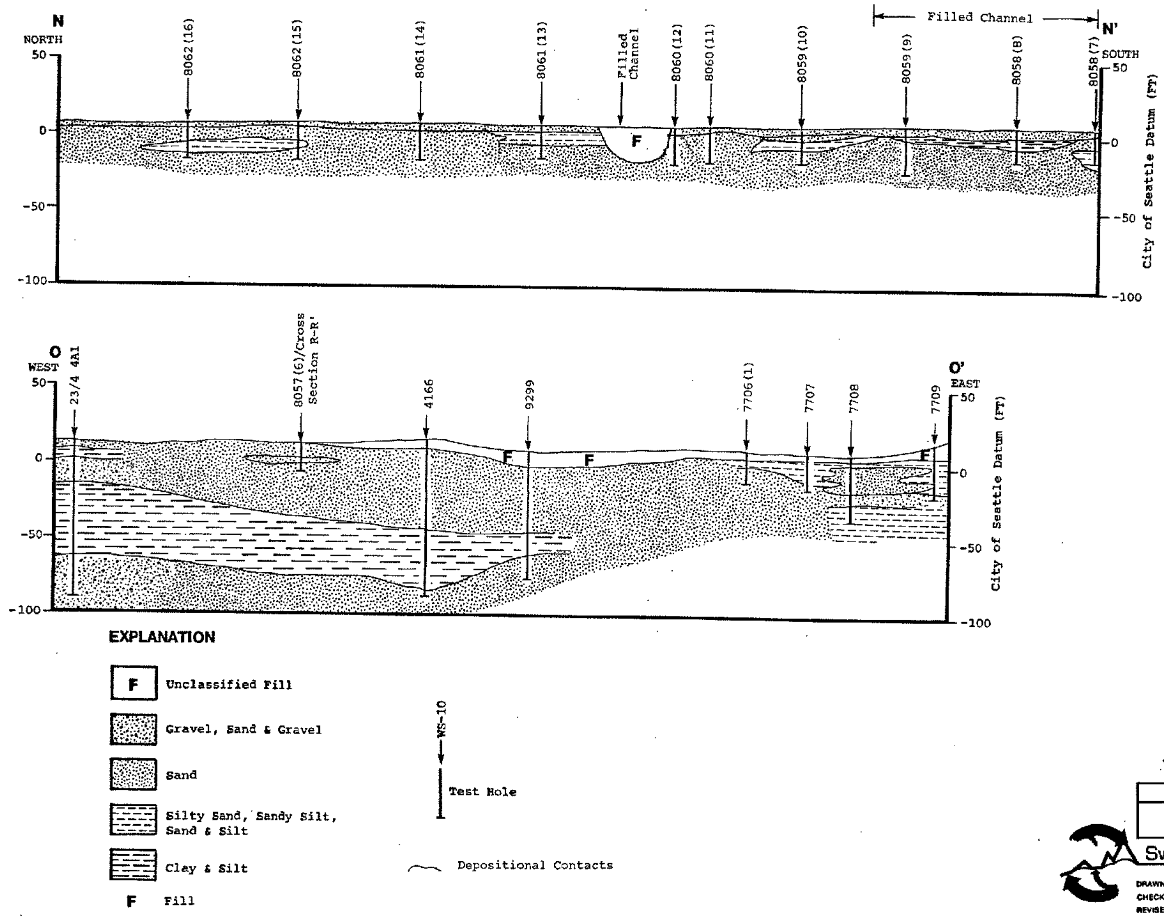
Potential Sources of Pollution. The northwest third of this subarea is paved with a low infiltration potential. The remainder includes radio towers, a dirt race track and open space with a high infiltration potential. No sources of pollution have been identified.

Geology. This subarea is covered with about 5 feet of silty sand and clayey soils and/or fill (see Figure IV-10 - Cross Sections P-P' & Q-Q'). Beneath the surficial deposits are about 20 feet of sand. Bedrock is shallow (about 30-40 feet deep).

Ground Water. Flow is directly toward the river. High recharge rates are expected from upland aquifers.

Subarea XIII

This subarea is bounded on the east and west by the slopes of the valley wall. The river and 116th Street South from the northern



0 600 1200

Horizontal Scale in Feet

Vertical Exaggeration x10

DUWAMISH GROUND WATER STUDY

Schematic Cross Sections
N-N' & O-O'

Sweet, Edwards & Associates

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Figure IV-9

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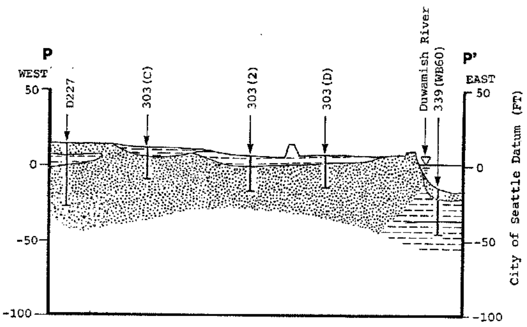

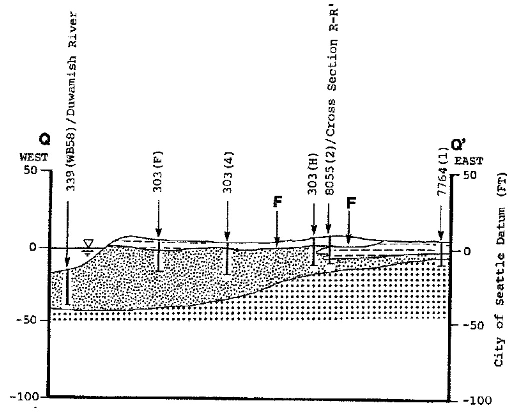

EXPLANATION

F Unclassified Fill

Gravel, Sand & Gravel

Sand

Silty Sand, Sandy Silt, Sand & Silt

Clay & Silt

Sandstone

WS-10

Test Hole

Depositional Contacts

0 600 1200

Horizontal Scale in Feet
Vertical Exaggeration x10

DUWAMISH GROUND WATER STUDY

Schematic Cross Sections
P-P' & Q-Q'

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Figure IV-10

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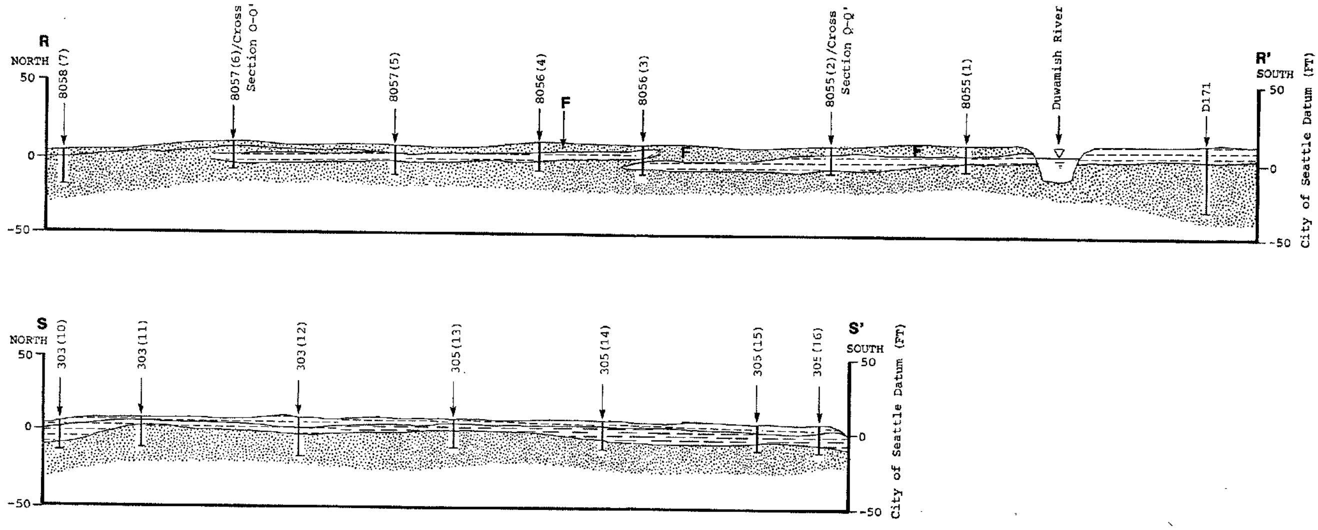
boundary. The southern boundary is the southern boundary of the study area. The subarea covers about 1.6 square miles and is dominated by river meanders.

Potential Sources of Pollution. The northern part of this subarea includes Allentown and is mostly residential with some industry. Infiltration potential is moderate. The southern part is mostly undeveloped with a golf course and small residential and industrial areas. There are no known contaminant sources west of the river. East of the river is the Seattle Rendering Works and the Sunset Demolition Landfill. Allentown and most likely the small residential and industrial areas are not connected to sewers. Potential contaminants include septic tank drainage (nitrates, chlorides, etc.), unknown tanked wastes, possible heavy metals and solvents.

Geology. Sedimentary and intrusive bedrock outcrop in several areas along the margins of this subarea and glacial till and outwash are well exposed in the valley walls. Surficial deposits include silty sand, silt, clay and peat to depths of 11 feet (see Figure IV-11 - Cross Sections R-R' and S-S'). Below the surficial materials is black sand to depths greater than 20 feet. Bedrock probably underlies the sand.

Ground Water. Ground water flow in most of the area is to the river.



EXPLANATION

F Unclassified Fill

Sand

Silty Sand, Sandy Silt, Sand & Silt

Clay & Silt

F Fill

WS-10 Test Hole

Depositional Contacts

0 600 1200

Horizontal Scale in Feet
Vertical Exaggeration x10

DUWAMISH GROUND WATER STUDY

Schematic Cross Section
R-R' & S-S'

Sweet, Edwards & Associates

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Figure IV-11

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SECTION V
MONITORING STRATEGY

This section presents our methodology in designing monitoring alternatives and a recommended program for implementation.

MONITORING GOALS

The goals and objectives of a monitoring program govern both the design and implementation of a monitoring program. The goal of the monitoring program for the Duwamish River Valley is to: "Determine contaminant contribution to the Duwamish River due to ground water inflow."

The basin was subdivided first into upland and valley floor areas, in part, to focus on that portion of the basin with the highest pollution potential. Based on the available data it is clear that the valley floor, due to the density of industrial development, has the higher potential for contamination. The valley floor was further divided into 13 subareas in order to identify parts of the valley floor which might possess a higher pollution potential. The northern half of the valley floor appears to have the highest potential for pollution, specifically subareas I-III, V, VIII, IX and XI.

The direct cost for implementing a monitoring program is heavily influenced by the number of pollutant sources, types of pollutants, the lack of data and the hydrogeology of the study area.

MONITORING PROGRAM DEVELOPMENT

The monitoring strategy for the Duwamish River Basin addresses:

- where to monitor,
- what to monitor,
- when to monitor,
- how to monitor, and
- cost of monitoring

Three alternative monitoring programs have been developed addressing each of the above. Due to data needs common to any monitoring program what, when and how to monitor are the same for each alternative. Only where and the cost are substantially different for the three alternatives.

Where to Monitor

Ground water and contaminant flow occur within a three dimensional system and therefore, monitoring locations must be defined both areally (site location) and with depth (aquifer locations).

Site Locations. Proper monitoring site locations are critical to achieving the goals of the monitoring progam. Unfortunately, when sufficient data are lacking, a substantial amount of time and money are at risk regardless of the approach used in selecting site locations. In order to recommend a cost effective monitoring program we have evaluated the following site location alternatives:

- o Alternative A: Grid
- o Alternative B: Point Source
- o Alternative C: Cross Channel

Each alternative has advantages and disadvantages with respect to achieving the monitoring goal.

Alternative A: Grid--The most comprehensive and risk free approach to achieving the monitoring goal is to employ a grid system which covers the entire valley floor. Grid spacing governs the number and location of monitoring wells. A number of approaches, mostly arbitrary, can be used to establish a grid spacing. The approach we employed was based on an estimate of ground water flow velocities and hydrodynamic dispersion calculated to have accrued since industrial development occurred in the basin. Two dominant parameters were considered: ground water flow rate and the median time period of potential introduction of contaminants.

Ground water flow rate was calculated using Darcy's Law, where:

$$v = \frac{Ki}{n}$$

v = velocity of flow in feet/day
K = coefficient of permeability
i = hydraulic gradient
n = effective porosity

Parameter values are for a silty sand which is the most common material type identified throughout the study area. Permeability was estimated at 10 feet/day based on our experience with similar materials and data developed by Burmeister, 1954.[18]

Porosity for silty sand was assumed to be 35 percent. An average hydraulic gradient of .002 was used based on an evaluation of ground water studies at Chempro and Boeing-Isaacson.[19,2] Chempro is on the margins of the valley floor and the Boeing-Isaacson data is from wells about 600 feet east of the river outside of tidal influence. The estimated ground water velocity therefore, is about 21 feet per year.

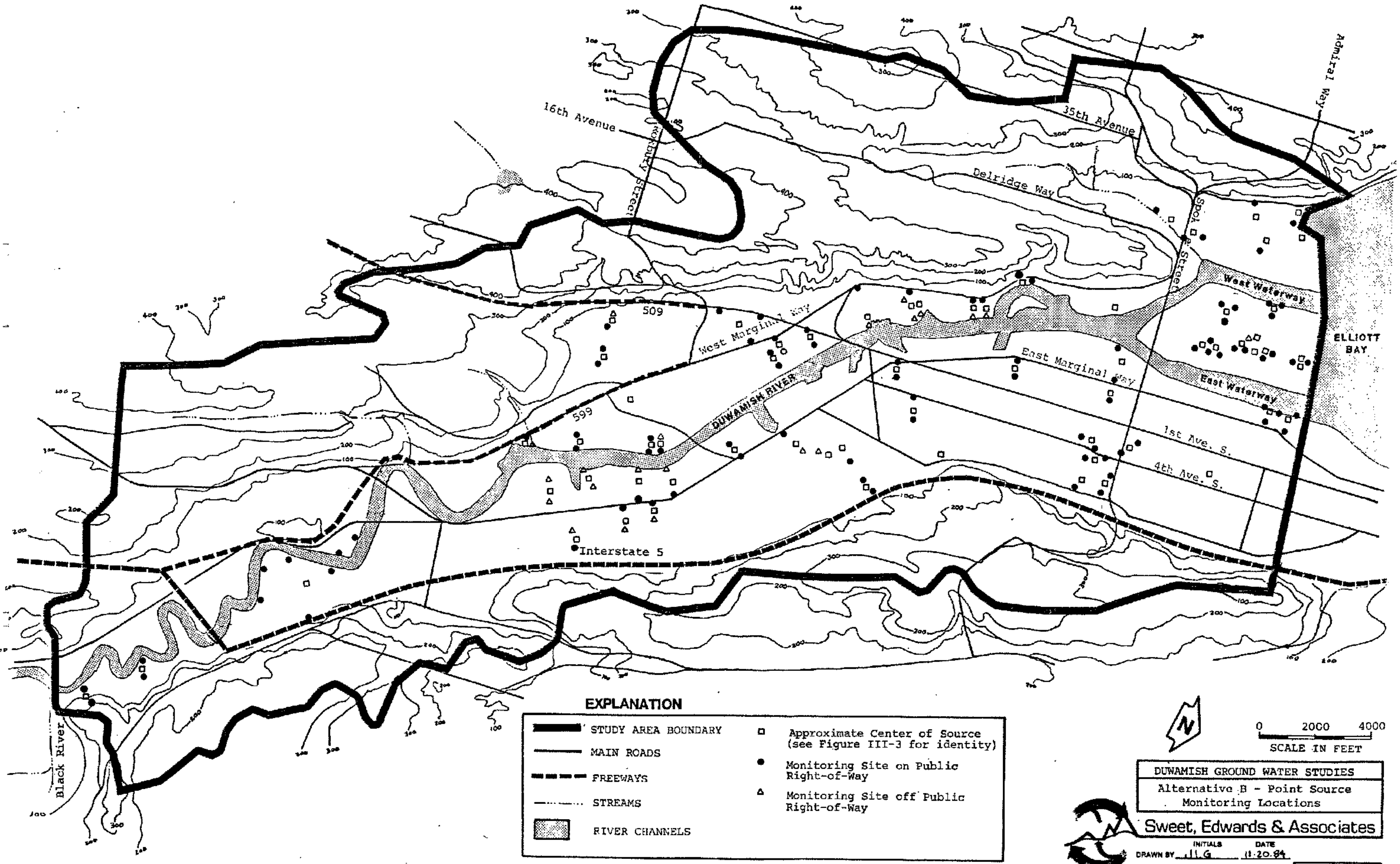
Heavy industrial development began after completion of the primary placement of fill (about 1915, refer to Appendix D). Therefore 1950, or 35 years ago, is considered the median time period of potential introduction of contaminants. Using this approach, the distance for contaminant movement due to ground water flow is assumed to be 735 feet. This analysis ignores tidal effects on the aquifer which may alter net rates of contaminant movement.

Allowing for diffusion, a grid spacing was conservatively chosen of roughly twice the estimated distance of contaminant movement. A 1500 foot grid spacing would provide for 151 monitoring well sites. In addition, 16 sites would be located in the upland areas based on access, geology and probable flow directions. Total number of wells required for Alternative A would be 167. Six river gauges and 12 continuous water level recorders would also be required.

The advantages of Alternative A monitoring would be complete coverage of the valley floor providing ample water level and water quality data to characterize hydrogeologic conditions and determine contaminant inflow to the river.

The major disadvantages of an Alternative A program would be its cost and the difficulty of locating many monitoring wells on private property.

Alternative B: Point Source locations--A point source monitoring program would site wells upgradient and downgradient of potential sources of pollution as identified in Table III-1 - Potential Sources of Pollution. Figure V-1 - Alternative B - Point Source Monitoring Locations shows the approximate location of monitoring well sites. Probable direction of ground water flow and zones of preferential flow (channels, etc.) were used in



Base Map: U.S.G.S. 7½' Quad. Duwamish Head, Seattle South & Des Moines

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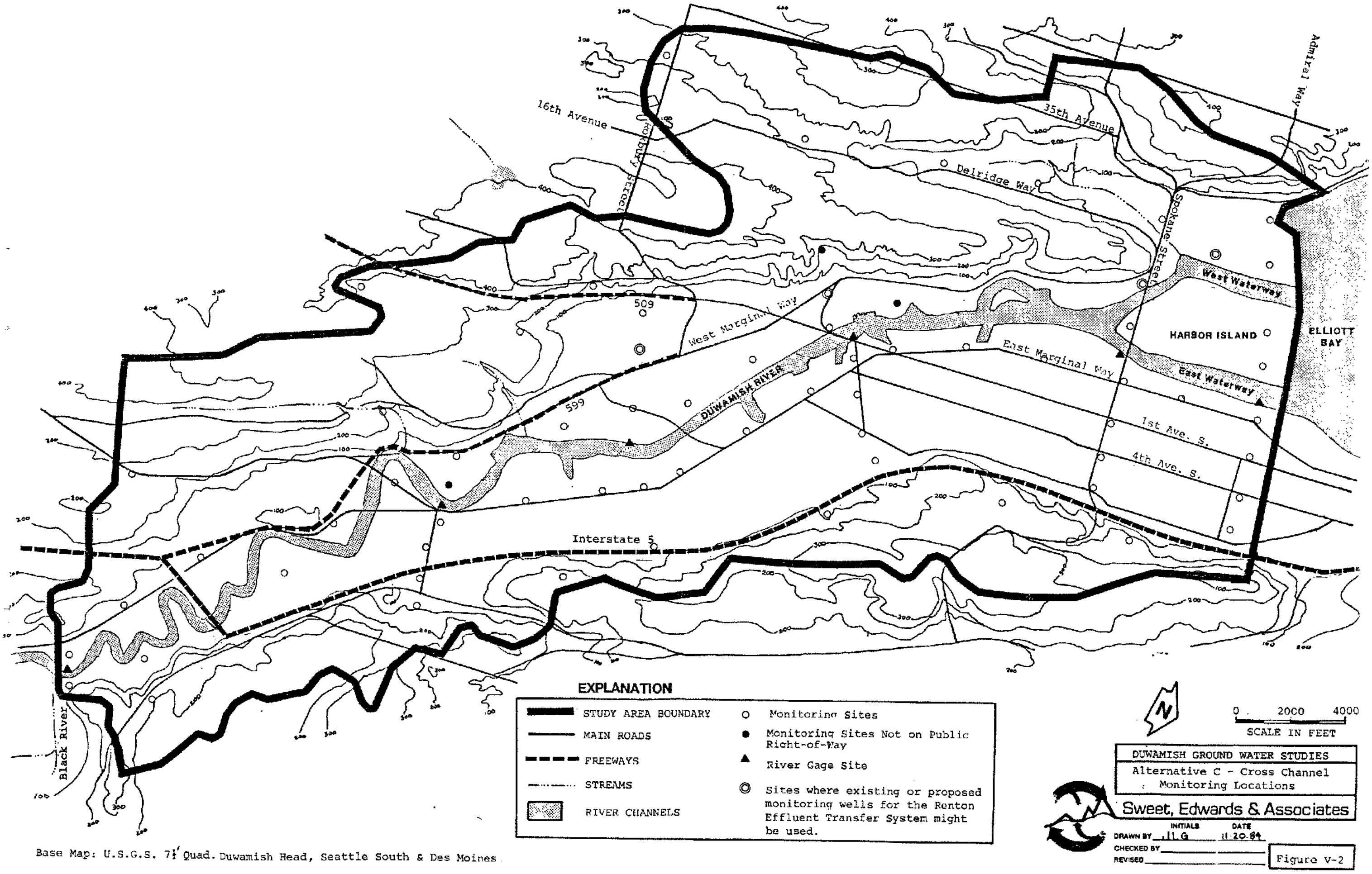
positioning the well site locations. Where possible, well sites were located on public right of way and placed up and downgradient of the potential source. Potential sources where monitoring programs are in place (i.e. Chempro, Boeing-Issacson, Terminal 105, etc.) have not been included. Data transfer should be initiated in these cases. A total of 112 monitoring wells are required under Alternative B, along with river gauges and continuous water level recorders.

The advantages of using Alternative B would be to reduce costs by focusing on the most likely areas of ground water contamination. If the entire system is employed, a sufficient density of wells would allow characterization of the ground water flow system in order to estimate ground water contamination contribution to the river.

The disadvantages of a point source approach would be its high cost, the inability to account for nonpoint or identify other point sources of contamination and the risk and unnecessary expense of installing monitoring wells around sites which may be potential sources, but in fact are not sources of contaminants. In addition, a system of this type would provide little flexibility with respect to implementation. Without the density and data of the entire system installed at a single time there would be insufficient data to estimate ground water inflow to the river.

Alternative C: Cross Channel--This monitoring approach focuses on defining the ground water flow characteristics of the basin and the assumption that ground water pollution increases downstream. Six cross channel (perpendicular to river flow) sections have been established based on the hydrogeology and industrial development as defined by subarea division (see Figure V-2 - Cross Channel Monitoring Locations). In addition, wells have been aligned parallel to the river in locations of preferential subsurface flow. As in Alternative A, 16 upland wells have been included in this approach. Two continuous water level recorders per cross channel section (one in a well and the other in the river) are included in the design to establish the influence of river levels, particularly tidal, on ground water levels. All well locations are in public right of way except where noted. A total of 69 monitoring sites are required for this program.

The advantages of this alternative are substantially lower cost, the ability to account for basin wide contamination (both point source and nonpoint source), sufficient coverage to determine



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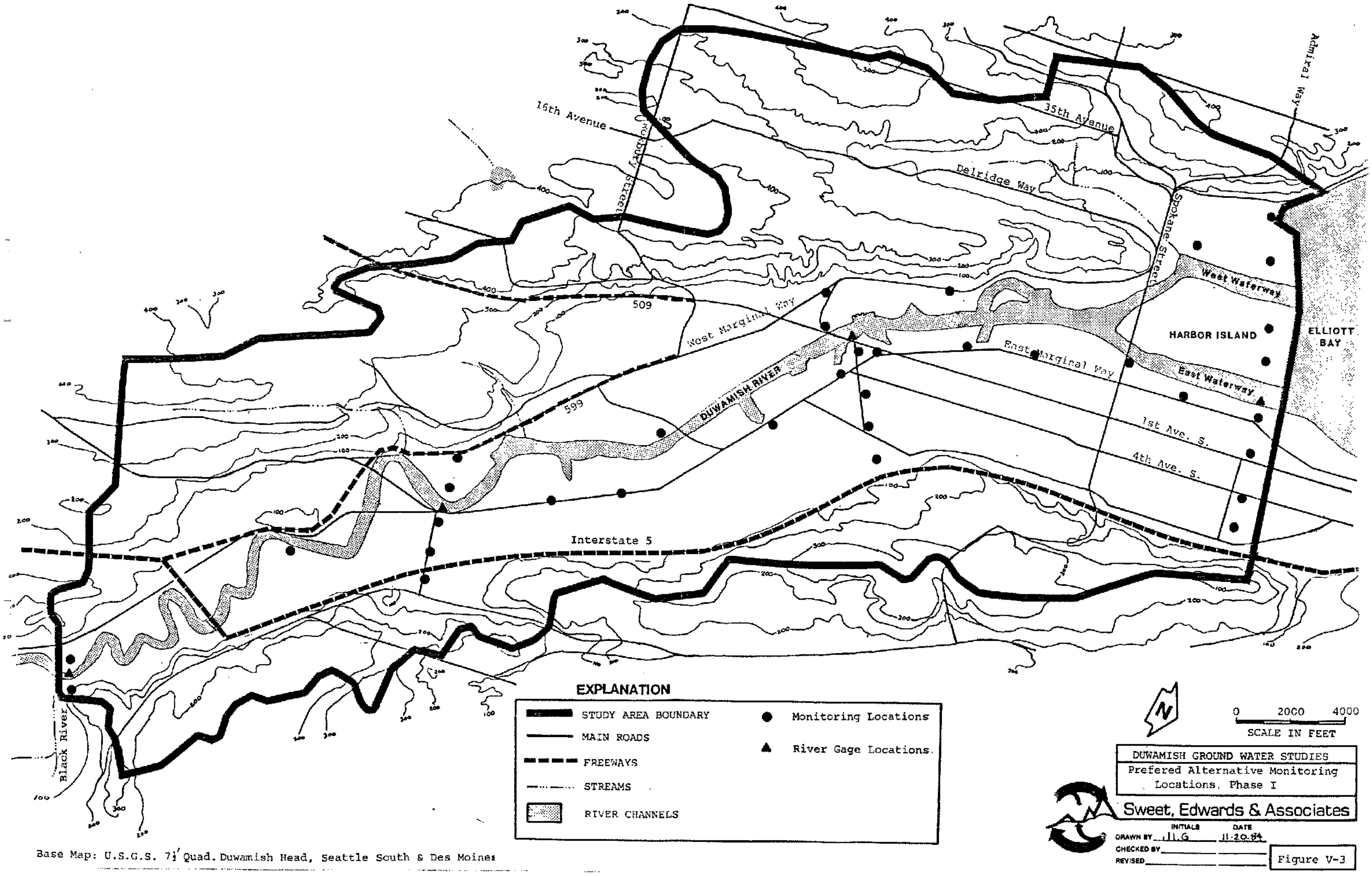
ground water inflow to the river and a considerable amount of flexibility with respect to phasing implementation. Several (4+) of the monitoring wells installed for the Renton Effluent Transfer System could be employed as part of this program reducing the total cost. The major disadvantage of this alternative would be the inability to identify specific sources of contamination.

Preferred Alternative--Based on our knowledge of the study area and experience in monitoring programs, we prefer Alternative C: Cross Channel Monitoring because of the lower cost and the flexibility afforded by this alternative. A phased program of implementation would reduce initial costs even further and allow options neither of the other alternatives would allow. Monitoring locations for the first phase installation are shown on Figure V-3 - Preferred Alternative Monitoring Locations - Phase I.

This approach breaks up the valley floor into four major subdivisions based on land use and hydrogeology. Ground water flow system and water quality data developed during the first one or two years of monitoring could be evaluated and based on this data, resources could be focused in later phases on the basin section where ground water contamination appears most prevalent. Upland monitoring would be postponed until later phases, when and if the upland data was considered necessary to achieve the project goals. In addition, subsequent phases of the cross channel monitoring could be augmented with selected point source monitoring as data warrants. Phasing would also allow location of additional monitoring wells using a more complete data base and thereby reduce the risk of installing unnecessary monitoring wells.

<u>Aquifer Locations</u>. In general, monitoring of the uppermost or first aquifer below the surface is preferable for identifying ground water contamination. However, in order to adequately characterize ground water flow in the basin and subsequently inflow to the river, it may be necessary to monitor deeper aquifers in later phases if warranted. Differences in hydrostatic pressures with depth will allow determination of recharge/discharge conditions and the construction of ground water flow paths to or away from the river. Therefore, it is recommended that all of the monitoring alternatives be phased to include facilities for monitoring both shallow and deep ground water conditions. Monitoring of deeper zones may be necessary to evaluate the attenuation and concentration of pollutants which might be vertically mobile.



DUWAMISH GROUND WATER STUDIES
Prefered Alternative Monitoring Locations, Phase I

Sweet, Edwards & Associates

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Figure V-3

Base Map: U.S.G.S. 7½' Quad. Duwamish Head, Seattle South & Des Moines

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What And When To Monitor

It will be necessary to collect and evaluate a substantial amount of hydrology data before a meaningful determination of ground water/estuarine flow system can be defined. The principal data required include water level data, water quality data and sediment data.

Water Level Data. Water level data are critical in determining the direction and rate of ground water flow. Due to the low elevation of most of the project area and the influence of river levels, very accurate (within a hundredth of a foot) water level measurements will be required if the data is to be meaningful. Elevations for measuring points at each facility will have to be surveyed and tied to a common datum. Water levels should be measured quarterly. In addition, continuous water level monitoring at selected locations should also be performed.

Water Quality Testing. The water quality parameters selected for monitoring significantly influence the cost of implementing and maintaining a monitoring program. Sampling parameters should be based on the types of waste which are common to the potential sources of pollution in the study area. Below we list the potential contaminants characterized in Section IV for the study area:

wood preservatives	petroleum products
PCBs	flue dust
heavy metals	high pH
cyanide	acids
arsenic species	calcium carbonate
methane	sodium hydroxide
solvents	fertilizers
acid and base neutral organics	greases
pesticides	other organics
pickling liquors	unknown contaminants
nitrates	
chlorides	

Unfortunately, this list is incomplete considering the number and type of industries in the study area, therefore we have limited monitoring parameters to two classes for the first two years of monitoring.

Class I: Indicator Parameters--This consists of the minimum level of sampling and testing to adequately characterize general water quality conditions in the basin and detect changes in the environment which might be expected from uncontrolled waste discharges (see Table V-1 - Class I: Indicator Parameters).

TABLE V-1

CLASS I: INDICATOR PARAMETERS

PARAMETER	TESTING
Temperature	Field
Conductivity	Field and Laboratory
pH	Field and Laboratory
Nitrate	Laboratory
Chloride	Laboratory
Sulphate	Laboratory
TOC (Total Organic Carbon)	Laboratory
TOX (Total Halogenated Hydrocarbons)	Laboratory
Cadmium	Laboratory
Copper	Laboratory
Chromium	Laboratory
Nickel	Laboratory
Lead	Laboratory
Zinc	Laboratory
Arsenic	Laboratory
Mercury	Laboratory

Frequency: Quarterly for first two years, semi-annually thereafter.

In order to establish a statistically credible data base, quadruplicate sampling and testing should be performed the first year on all Class I - Indicator Parameters.

Class II: Priority Pollutants as listed in CFR 140-16, regulation of hazardous substances[20] (see Table V-2 - Priority Pollutant Parameters). These constituents are recommended because of the wide range of potential contaminants present in the basin. All wells should be tested once in the first year, but 25 percent are estimated to require sampling in the second year.

At the end of the first and second year of monitoring the water quality data should be evaluated and both classes of monitoring

TABLE V-2

CLASS I: PRIORITY POLLUTANT PARAMETERS

	ORGANICS					
METALS	VOLATILE COMPOUNDS	BASE/NEUTRAL COMPOUNDS	ACID COMPOUNDS	PESTICIDES	DIOXIN	GENERAL
Antimony	Acrolein	Acenaphthene	2-Chlorophenol	Aldrin	2,3,7,8-Tetrachloro-dibenzo-p-dioxin	Asbestos
Arsenic	Acrylonitrile	Acenaphthylene	2,4-Dichlorophenol	a-BHC		Cyanide
Beryllium	Benzene	Anthracene	2,4-Dimethylphenol	b-BHC		Phenols, Total
Cadmium	Bromodichloromethane	Benzidine	4,6-Dinitro 2-methylphenol	d-BHC		
Chromium	Bromomethane	Benzo(a)anthracene	2,4-Dinitrophenol	g-BHC(Lindane)		
Copper	Bromoform	Benzo(a)pyrene	2-Nitrophenol	Chlordane		
Lead	Carbon tetrachloride	Benzo(b)fluoranthene	4-Nitrophenol	4,4'-DDD		
Mercury	Chlorobenzene	Benzo(g,h,i)perylene	4-Chloro-3-methylphenol	4,4'-DDE		
Nickel	Chloroethane	Benzo(k)fluoranthene	Pentachlorophenol	4,4'-DDT		
Selenium	2-Chloroethylvinyl ether	Bis(2-chloroethoxy)methane	Phenol	Dieldrin		
Silver	Chloroform	Bis(2-chloroethyl)ether	2,4,6-Trichlorophenol	Endosulfan I		
Thallium	Chloromethane	Bis(2-chloroisopropyl)ether		Endosulfan II		
Zinc	Dibromochloromethane	Bis(2-ethylhexyl)phthalate		Endosulfan sulfate		
	1,1-Dichloroethane	4-Bromophenyl phenyl ether		Endrin		
	1,2-Dichloroethane	Butyl benzyl phthalate		Endrin aldehyde		
	1,1-Dichloroethene	2-Chloronaphthalene		Heptachlor		
	trans-1,2-Dichloroethene	4-Chlorophenyl phenyl ether		Heptachlor-epozide		
	1,2-Dichloropropane	Chrysene		PCB-1016		
	cis-1,3-Dichloropropene	Dibenzo(a,h)anthracene		PCB-1221		
	trans-1,3-Dichloropropene	1,2-Dichlorobenzene		PCB-1232		
	Ethylbenzene	1,3-Dichlorobenzene		PCB-1242		
	Methylene chloride	1,4-Dichlorobenzene		PCB-1248		
	1,1,2,2-Tetrachloroethane	3,3'-Dichlorobenzidine		PCB-1254		
	Tetrachloroethene (PCE)	Diethyl phthalate		PCB-1260		
	Toluene	Dimethyl phthalate		Toxaphene		
	1,1,1-Trichloroethane	Di-n-Butyl phthalate				
	1,1,2-Trichloroethane	2,4-Dinitrotoluene				
	Trichloroethene (TCE)	2,6-Dinitrotoluene				
	Vinyl Chloride	Di-n-Octyl phthalate				
		1,2-Diphenylhydrazine				
		Fluoranthene				
		Fluorene				
		Hexachlorobenzene				
		Hexachlorobutadiene				
		Hexachlorocyclopentadiene				
		Hexachloroethane				
		Indeno (1,2,3-c,d)pyrene				
		Isophorone				
		Naphthalene				
		Nitrobenzene				
		N-Nitrosodimethylamine				
		N-Nitrosodipropylamine				
		N-Nitrosodiphenylamine				
		Phenanthrene				
		Pyrene				
		1,2,4-Trichlorobenzene				

parameters modified as appropriate to focus on identified ground water contaminants and reduce costs.

Sediment Testing. In order to determine inflow to the river a better understanding of the hydraulic conductivity (permeability) of the saturated zone is required. Permeability estimates can be made from grain size data. During monitoring well drilling, the first 5 feet of saturated sediment should be sampled continuously with additional samples taken at 5-foot intervals. Selected sediment samples should then be analyzed for grain size distribution (sieve and/or hydrometer). The aquifer permeability estimates resulting from grain size analysis may indicate that short term (2-6 hours) pump tests and or drum infiltrometer field tests are warranted in some wells.

Soil samples obtained during drilling should be screened using photoionization for volatile organics. The field screen will indicate if gas chromatograph testing for compound identification is warranted. Soil samples should be split and a portion held for later inorganics analysis if needed.

Saline Ground Water Effects

To evaluate contaminant transport across the subsurface saline/fresh ground water interface, a series of shallow monitoring wells should be installed at a site with a contaminant plume containing both dissolved inorganic and organic constituents. Tracers and spiking with a wide variety of parameters will be required to determine which contaminants are mobilized by the saline waters and which are demobilized. Changes in ground water quality as the contaminants cross the interface would be determined by sampling the wells and statistically comparing the water quality on each side of the interface.

Because the interface is present near shore areas in the estuary, the same monitoring system would be used to evaluate the effect of tide induced changes in ground water flow direction on net contaminant transport.

Further regional study of ground water contaminant loading to the estuary must include such an investigation because the saline/fresh water interface is believed to be present at varying distances from the river bank throughout the industrialized portion of the basin. The design and effectiveness of remedial actions implemented to clean up ground water should account for the interface effect on contaminant transport.

Since a similar interface occurs in industrialized estuaries nationwide, such applied research should be grant eligible through the U.S. Geological Survey or EPA.

How To Monitor

Monitoring ground water requires sophisticated facilities, equipment and procedures.

Facilities. Access to the ground water system is via wells. Specially constructed monitoring wells provide for accurate water level measurements, collection of representative water samples and quality assurance/quality control. Only through the use of properly installed monitoring wells can we be assured of what aquifer is being monitored and if that aquifer is effectively isolated.

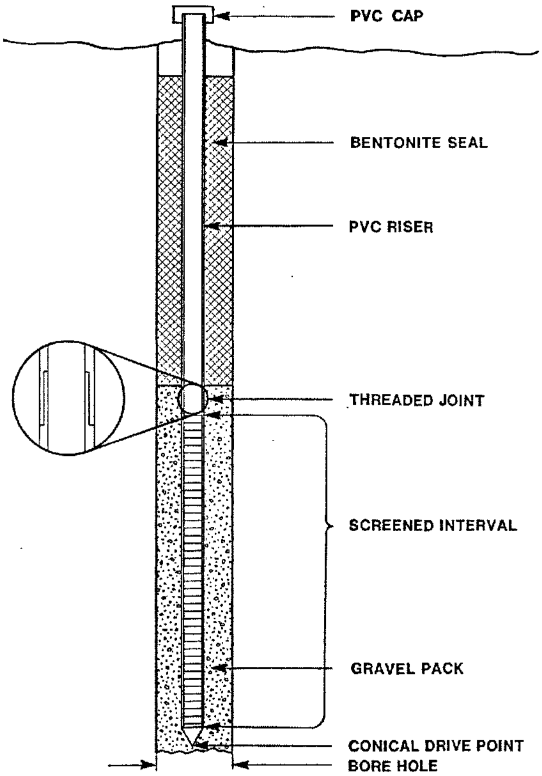
Proper installation of specially constructed monitoring wells requires the use of experienced personnel, proper equipment, materials and procedures. For the Duwamish Basin two types of wells are required; single completion and multiple completion (see Figure V-4 - Single & Double Completion Monitoring Wells).

The monitoring wells should be drilled using an air rotary drill rig with casing driver or hollow stem auger. For air rotary drilling in upland and bedrock areas, a minimum 6- to 8-inch diameter hole would be drilled while simultaneously advancing a minimum 6- to 8-inch diameter steel casing (single completion is 6-inches, double completion is 8-12 inches). The depths of the borings will range from 40-120 feet.

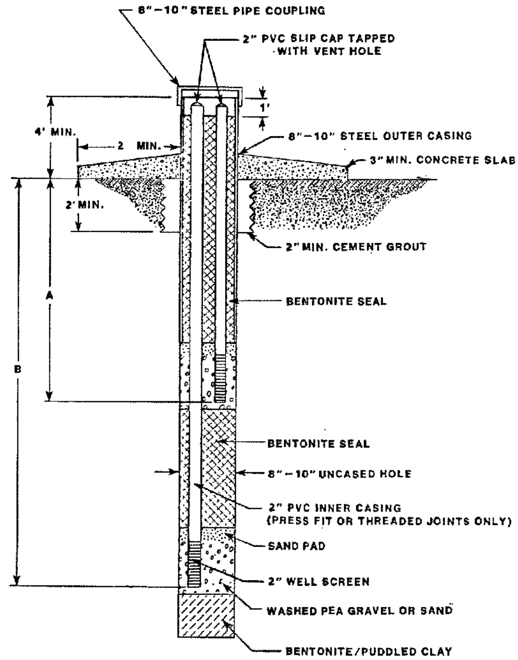
The shallow wells drilled in valley floor materials would be drilled with a 6-inch inside diameter hollow stem auger. Rotary wash capability will be required in many areas where loose sand and silty sand is present. The depths of the borings will range from 20 to 60 feet. Access sufficient to accomodate 40 foot long rigs (drill rig and pipe truck) is necessary. Access to water for drilling will be necessary.

Upon completion of drilling, 2-inch diameter Schedule 80 PVC well screen(s) (slot size .010 to .020 inch) should be installed opposite the water bearing formation. A push point bottom cap will be fixed to the screen. The screen would be attached to the

SINGLE COMPLETION MONITORING WELL



DOUBLE COMPLETION MONITORING WELL



DUWAMISH GROUND WATER STUDY

Single & Double Completion Monitoring Wells

Sweet, Edwards & Associates

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Figure V-4

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bottom of a 2-inch Schedule 80 PVC casing(s) rising 1 to 2 feet above ground surface. A top cap would be provided with an air vent hole. Only threaded couplings should be used. No solvent welded or slip couplings should be used.

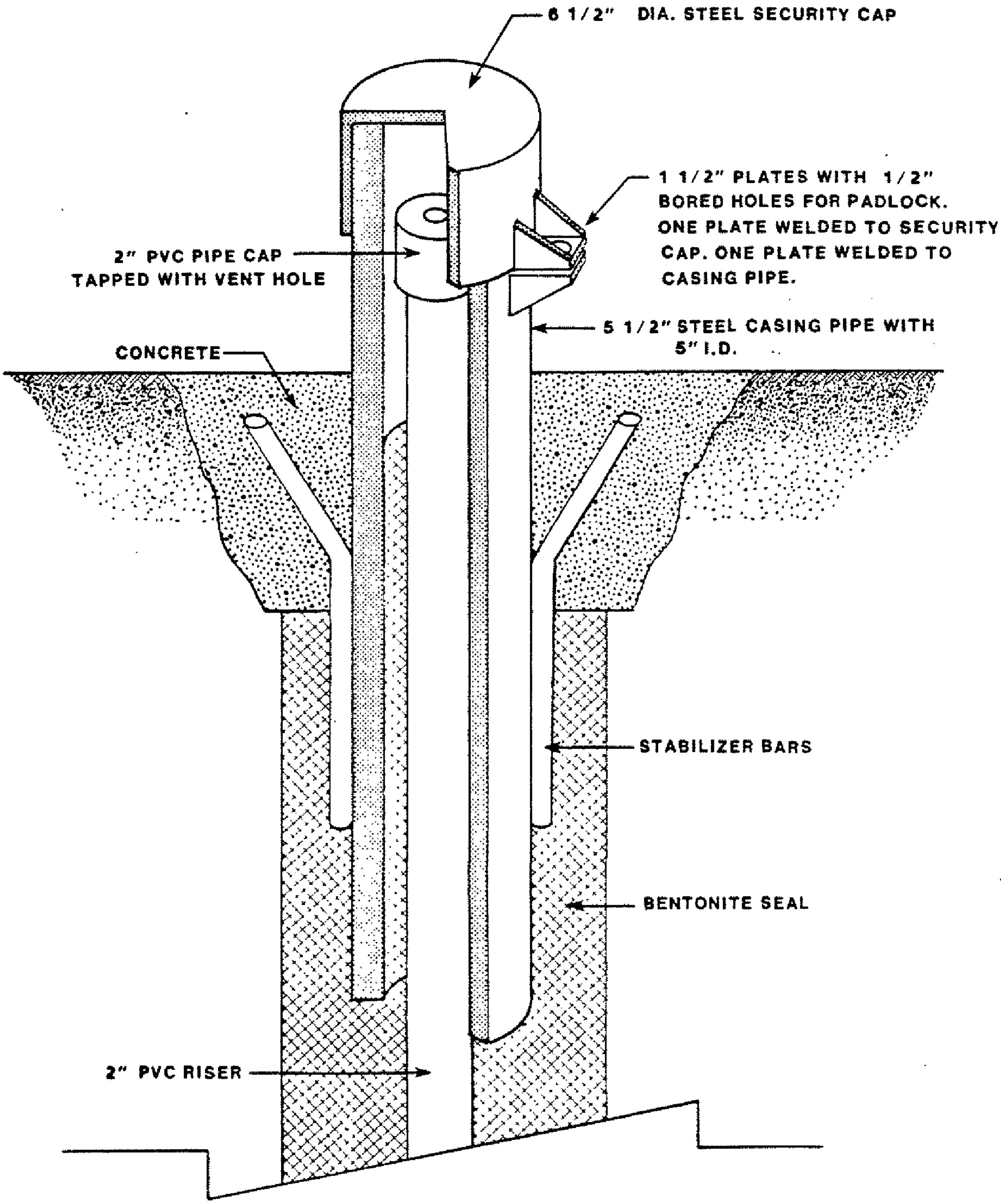
After the screen and casing have been installed 1/4- to 3/8-inch sand or gravel filter should be placed from the bottom of the hole to a depth designated by the geologist. A minimum 2 foot thick plug using bentonite pellets would be placed on top of the filter pack. For single completion wells the remainder of the hole would be filled with a bentonite slurry. For double completion wells an isolating plug (bentonite pellets) should be placed below the upper screen and above the lower screen at a depth designated by the geologist.

Simultaneously with the installation of the gravel pack and bentonite, the steel casing or auger should be removed from the hole. Upon removal of the steel casing a 6-inch diameter locking security casing should be cemented into place to protect the monitoring well from vandalism (see Figure V-5 - Monitoring Well Security Casing).

After completion, the well is developed for 2-4 hours using filtered air. The purpose of development is to remove fines from within the casing, screen, and annular gravel pack to ensure hydraulic continuity with the water bearing formation. All well construction must be performed by a licensed water well contractor. An experienced geologist should log the holes and supervise the placement of screen, casing and gravel pack, well seal and development.

For wells fixed with continuous water level monitors (Stephens Type F recorder), minimum 4" internal diameter casing and screen will be required. For river level monitors a 6-inch diameter culvert pipe will be adequate. A 36-inch diameter, locked, protective casing would be installed to prevent vandalism of the continuous recorders.

<u>Monitoring Equipment</u>. Based on the assumption that METRO will want to train and employ their own staff for actual monitoring operations, we have listed the minimum equipment requirements for monitoring (see Table V-3 - Monitoring Equipment).



DUWAMISH GROUND WATER STUDY
Monitoring Well Security Casing
Sweet, Edwards & Associates

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Figure V-5

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TABLE V-3

MONITORING EQUIPMENT

ITEM	APPROXIMATE PRICE
Geotech peristaltic pump, series-2	$ 575
Geotech backflushing filter	150
(100) .45 micron disposable filters	200
Pre-filters	50
I.E.A. syringe sampler w/200 ft. of tubing	1,400
Vacuum pump	175
Middleburg pump complete	2,600
Electric water level probe	230
Centrifugal pump	400
Model 21 Beckman pH meter	375
Chemtrex Model 700 conductivity meter	275
12 volt marine battery	70
Teflon bailer, Galtek #219-4	135
Flow through cell, Sweet-Edwards	225

Note: The above manufacturers listed are not an endorsement, but are provided as a guideline for the type of equipment needed. Several manufacturers exist for most items.

Miscellaneous cleaning equipment and disposable material includes buckets, brushes, soap, methanol, deionized and distilled water, etc.

Total cost of the monitoring equipment is approximately $7,000. In addition to the above equipment after the second year of monitoring, it may be cost effective to outfit selected monitoring wells with dedicated gas operated sampling pumps and piezometers such as the "Well Wizard" or equivalent. Dedicated pumps, while initially quite expensive ($1,200 to $1,700), substantially reduce long term monitoring costs because of reduced field time ($300-$500 per well per year) and provide for consistent quality control.

Monitoring Procedures. Adherance to proper monitoring procedures are necessary to obtain consistent and reliable water quality data. Appendix E is a general procedures manual developed to assist METRO in their monitoring program.

Cost Of Monitoring

Cost estimates for implementing the various alternatives have been developed based on the unit costs presented in Table V-4 - Monitor Well Construction. Average well depths of 40' and 120' were used in the cost estimate. Actual depth will be dependent on field determinations.

Table V-5 -Total Cost Alternatives presents the cost of well installation and the first two years of monitoring for each alternative.

TABLE V-4

MONITORING WELL CONSTRUCTION - UNIT COSTS

ITEM	UNIT COST	HOLLOW STEM AUGER SINGLE COMPLETION(40')	HOLLOW STEM AUGER DOUBLE COMPLETION(40')	AIR ROTARY SINGLE COMPLETION(40')	AIR ROTARY DOUBLE COMPLETION(40')	AIR ROTARY SINGLE COMPLETION(120')
Drilling: Air rotary	$23.00/ft-8"	---	---	$ 920.00	$ 920.00	$2,760.00
Hollow stem auger	$12.00/ft-12"	$ 480.00	$ 480.00	---	---	---
2" Sch. 80 PVC casing threaded	$2.50/ft	100.00	150.00	100.00	150.00	300.00
2" Sch. 80 PVC screen	$3.00/ft	45.00	90.00	45.00	90.00	45.00
Gravel	$6/ft-6" hole; $8/ft-8-12" hole	84.00	224.00	84.00	224.00	112.00
Concrete	$6.00/well	6.00	6.00	6.00	6.00	6.00
Bentonite pellets	$50/ft-6" hole; $65/ft-8-12" hole	100.00	650.00	100.00	650.00	130.00
Security casing and lock	$80/6" hole; $90/8" hole	80.00	80.00	90.00	90.00	90.00
End plug and cap	$18.00/installation	18.00	36.00	18.00	36.00	18.00
Bentonite powder	$10.00/sack	30.00	20.00	30.00	20.00	40.00
Installation	$90.00/hour	180.00	360.00	190.00	360.00	360.00
Inspection	$50.00/hour	800.00	900.00	800.00	900.00	1,200.00
Development	$45.00/hour	90.00	180.00	90.00	180.00	360.00
Survey	$360/well	360.00	360.00	360.00	360.00	360.00
Mob/demob	$90.00/hour	180.00	180.00	180.00	180.00	180.00
Additional soil samples	$15.00/sample	60.00	60.00	60.00	60.00	60.00
Soil sample analysis	$450/well	450.00	450.00	450.00	450.00	450.00
TOTAL		$3,063.00	$4,226.00	$3,523.00	$4,676.00	$6,471.00

OTHER: Continuous recorders (with housing facilities) $1,200/each.

Sampling Costs Per Installation

Class I testing: Quadruplicate $685/run, Single $200/run.

Class II testing: $1,200/run.

Sampling labor $50/hour = $125/run (first year)

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TABLE V-5

TOTAL COSTS - ALTERNATIVES

MONITORING STRATEGY	DRILLING METHOD	WELL CONSTRUCTION	NO. OF WELLS	INSTALLATION COSTS	FIRST YEAR SAMPLING/ TESTING COSTS	SUBSEQUENT YEAR SAMPLING/ TESTING COSTS	TOTAL FIRST TWO YEARS
Alternative A: Grid	Hollow stem auger	Single completion(40')	34	$104,142	$138,210	$ 40,800	$ 283.152
		Double completion(40')	101	426,826	821,130	242,400	1,490,356
	Air rotary	Single completion(40')	4	14,092	16,260	4,800	35,152
		Double completion(40')	12	56,112	97,560	28,800	182,472
		Single completion(120')	16	103,536	65,040	19,200	187,776
		Continuous recorders	6	7,200	---	---	7,200
				$711,908	$1,138,200	$336,000	$2,186,108
Alternative B: Point Source	Hollow stem auger	Double completion(40')	112	$473,312	$910,560	$268,800	$1,652,672
		Continuous recorders	6	7,200	---	---	7,200
				$480,512	$910,560	$268,800	$1,659,872
Alternative C: Cross Channel	Hollow stem auger	Single completion(40')	8	$ 24,504	$ 32,520	$ 9,600	$ 66,624
		Double completion(40')	39	164,814	317,070	93,600	575,484
	Air rotary	Double completion(40')	6	28,056	48,780	14,400	91,236
		Single completion(120')	16	103,536	65,040	19,200	187,776
		Continuous recorders	12	14,400	---	---	14,400
				$335,310	$463,410	$136,800	$ 935,520
Preferred Alternative	Hollow stem auger	Single completion(40')	8	$ 24,504	$ 32,520	$ 9,600	$ 66,624
		Double completion(40')	23	97,198	186,990	55,200	339,388
	Air rotary	Double completion(40')	3	14,028	24,390	7,200	45,618
		Continuous recorders	8	9,600	---	---	9,600
				$145,330	$243,900	$ 72,000	$ 461,230

APPENDIX A

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APPENDIX B

GLOSSARY

Appendix B

Glossary of Terms

Ablation - Processes by which snow and ice are lost from a glacier

Adsorption - Adhesion of molecules or ions to the surfaces of solid bodies with which they are in contact

Alluvium - All detrital deposits from modern rivers

Aquifer - Stratum or zone below the surface of the earth capable of producing water as from a well

Aquitard - Fine grained sediments which impede the movement of ground water

Attenuation - Reduction in concentration due to dilution, dispersion, or degradation

Bedrock - Any solid rock exposed at the surface of the earth or overlain by unconsolidated material

Drift - Deposits resulting from glacial activity including till, outwash and lacustrine sediments

Estuarine - Of, pertaining to, or formed in an estuary

Fissility - A property of splitting easily along closely spaced parallel planes

Flocculation - The process of separating suspended solids by chemical creation of clumps or flocs

Fluvial - Of, or pertaining to, rivers

Ice Sheet - A glacier forming in continuous cover over a land surface with the ice moving outward in many directions

Lacustrine - Pertaining to, produced by, or found in a lake

Leachate - A solution obtained by leaching, as by water percolating through solid waste

Lodgement Till - Till deposited beneath a moving glacier

Meander - One of a series of looplike bends in the course of a stream which is flowing at grade

Organic - Any compound containing carbon

Oxbow - A crescent shaped lake formed in an abandoned river bend that is separated from the main stream

Pleistocene Epoch - Division of geologic time that includes the recent glacial age and ended with the disappearance of the last ice sheet

Quaternary Period - Division of geologic time from 11,000 years ago to 2.5 million years ago that includes both the Pleistocene and Holocene (Recent) epochs

Stade - A substage of a glacial stade marked by glacial readvance

Stratified - Formed or lying beds, layers of strata

Tertiary - Geologic period that preceeded the Quaternary (2.5-60 million years ago)

Till - Poorly sorted glacial sediment generally dense, hard, with low permeability, and resembling concrete in appearance

APPENDIX C

INFORMATION SOURCES AND CONTACTS

APPENDIX C

This Appendix lists:

1. Agencies contacted for information - Attachment A

2. Private companies contacted for information - Attachment B

3. Companies contacted by letter for information - Attachment C

4. A summary of known existing ground water data from private companies and its availablilty - Attachment D

ATTACHMENT A

AGENCIES CONTACTED FOR INFORMATION
DUWAMISH GROUND WATER STUDIES

U.S. Government - Environmental Protection Agency

Jack Sceva - meeting 11/14/84
George Hoeffer - telephone contact 11/15/84
Mike Brown - telephone contact 11/15/84
Jim Everts - telephone contact 11/15/84
Phil Wong - telephone contact 11/21/84
Chuck Rice - telephone contact 11/21/84

U.S. Government - National Oceanic and Atmospheric Administration

Herb Curl - telephone contact 1/17/85

U.S. Government - Army Corps of Engineers

Dick Galster - telephone contact 11/8/84

U.S. Geological Survey - Water Resources Division

Rod Williams - telephone contact 11/8/84

State of Washington - Department of Ecology

John Conroy - meeting 11/19/84
John Littler - telephone contact 12/6/84
Gary Brugger - telephone contact 12/14/84
Mary Kautz - meeting 2/7/85

State of Washington - Department of Social and Health Services

Bob James - telephone contact 11/7/84
Nancy Steinfort - meeting 11/8/84, followed by telephone conversations

King County - Dept. of Health Services - Environmental Health

Larry Kirchener - telephone contact 11/7/84
Jim Henrickson - Southwest Service Center - telephone contact 11/7/84
Greg Bishop - telephone contact 2/5/85

ATTACHMENT A, continued

King County - Department of Public Works

Tom Lews - telephone contact 11/8/84

Andy Levesque - Earth Scientist - telephone contact 11/8/84

King County - Building and Land Division

Dr. Charlie Fulmer - telephone contact 11/9/84

King County - Soils Division

Technician - telephone contact 11/8/84

King County Planning Department - Resource Planning

Dave Clark - telephone contact 11/8/84

City of Seattle - Office of Intergovernmental Relations

Chuck Kleeburg - telephone contact 11/30/84

City of Seattle - Department of Construction and Land Use

Elsie Husizier - telephone contact 11/13/84

City of Seattle - Materials Laboratory

Technician - telephone contact 11/8/84

City of Seattle - Engineering Department

Peter G. Dundar - meetings 11/8/84 and 11/14/84

Mark Edens - telephone contact 3/6/85

Seattle City Solid Waste

Mel Andriesen - telephone contact 12/14/84

Port of Seattle

Bob Wells - telephone contact 12/4/84

Ann Farr - telephone contact 3/6/85

ATTACHMENT B

PRIVATE COMPANIES CONTACTED FOR INFORMATION
DUWAMISH GROUND WATER STUDIES

Duwamish Industrial Council

Kirk Thomson, representative; Don Stark, Consultant - meeting 11/29/84

Briefed the Council representatives on the project and requested cooperation with the effort.

Seattle City Light

Tim Kroll - telephone contaact 11/30/84

No ground water studies have been conducted by City of Light in the Duwamish. Described PCB contamination at the Georgetown Plant and the 4th and Spokane Street pole yard.

Northwest Cooperage

Herman Trofsky - telephone contact 12/3/84

Have not conducted any studies. Referred to testing labs for information.

High priority Haz Wst Site
EPA scheduled inves 1-86

Seattle Iron and Metals Corporation

David and Irving Siddell - telephone contact 11/30/84

Have conducted no ground water studies.

Sternhoff Metals

Irving Sternhoff - telephone contact 12/3/84

Does not know of any ground water studies at Duwamish facility. Area does not drain well.

ATTACHMENT B, continued

Lone Star Industries

Ken Rowen - telephone contact 12/3/84

Have not conducted any ground water studies to his knowledge. Have done soil testing for structures, which is available.

Chevron USA

Dave Feiglstock - telephone contact 11/29/84

Chevron property is being sold. They have several monitoring wells currently in place which will be abandoned. DOE has data from wells. DOE contacted 11/19/83, had not provided Chevron report as of 4/29/85.

SeaFab Metals Company

N.P. Jensen - written communication 1/23/85

Provided copy of well installation and observation report.

Converse Consultants

Steve Sagstad - meeting 3/6/85

Made available unpublished boring logs for RETS project.

Advance Electroplating

Randy Howorth - telephone contact 3/18/85

Knows of no hydrogeologic or subsurface studies

ATTACHMENT B, continued

Bethlehem Steel

Laura Mork - message left on 3/14/85 & 3/18/85

Did not return calls. On vacation week of 3/17-3/22. Summary report on Ground Water Sampling and Monitoring provided by Tom Hubbard of METRO.

The Boeing Company

Kirk S. Thomson - written communication 2/15/85

Stated that all relevant data given to DCLU or DOE and recommends contacting those sources.

Constructors Pamco

Mr. Jones (Richard Scheuman on leave until 3/31/85) - telephone contact 3/14/85

Knows of no hydrogeologic or subsurface studies.

Duwamish Shipyard, Inc.

Donald A. Meberg - written communication 2/6/85

Stated that they have not conducted any ground water studies on their property.

Ideal Basic Industries

Ron Wallis - telephone contact 1/17/85

Has not conducted nor is planning any ground water studies.

ATTACHMENT B, continued

Earle M. Jorgensen Company

John Lavillette - telephone contact 3/18/85

Has no ground water or subsurface information.

Kenworth Truck Company

Rusty Wailes - telephone contact 3/14/85

Described water inflow to excavations previously conducted and sent copies of foundation boring logs.

Lockheed Shipbuilding, Inc.

John Lane - telephone contact 3/22/85

No ground water studies have been conducted. Will send boring logs from recent foundation study. Not received as of 4/28/85.

Manson Construction and Engineering

Lester Hillis - telephone contact 3/14/85

Have not performed any hydrogeologic studies.

Monsanto Company

Mel Miller - telephone contact 3/14/85

Have not conducted any ground water studies. Will send available foundation boring logs. Not received at of 4/28/85.

ATTACHMENT B, continued

Northwestern Glass

George Gatchet - telephone contact 3/14/85

Knows of several borings conducted for foundation studies; will send copies of ones available. Not received as of 4/28/85.

Todd Pacific Shipyards Corporation

Jim Anderson - telephone contact 3/14/85

Have not conducted any ground water studies and only pilings driven below surface. No excavations or borings.

Marine Power and Equipment Company

Phil Ballinger - telephone contact 3/22/85

Have no ground water or subsurface information.

Chemical Processors, Inc.

Michael P. Keller - written communication 1/17/85

Granted permission for Harper-Owes to release Appendix A of the Georgetown Plant Ground Water Studies. Data has been received.

Shell

Mr. Clarkson - telephone contacts 3/14 & 3/22

Will contact environmental person responsible when they return from vacation on 4/1/85.

ATTACHMENT B, continued

Atlantic Richfield Company

Robert Bunten - telephone contact 3/14/85

Stated he had thoroughly searched records after a recent request by METRO for data regarding their monitoring wells. Found little information. Wells were drilled approximately 18 years ago and two metal casings remain intact.

Wyckoff Company

William Carins - telephone contact 1/22/85

Stated that they would like to help but all data was in litigation and unavailable for release.

GATX Tank Storage Terminals

Greg Leese - telephone contact 3/14/85

Knows of no ground water or subsurface data. Their newest tank was constructed in 1954.

Rabanco

Steve Banchero - telephone contact 3/19/85

Have not conducted any ground water studies and is not sure if there are any boring logs available.

ATTACHMENT C

COMPANIES CONTACTED BY LETTER
DUWAMISH GROUND WATER STUDIES

Advance Electroplating - Randy Haworth
Bethlehem Steel - Laura Mork
The Boeing Company - Kirk Thomson
Constructors - Pamco - Richard Scheuman
The Duwamish Shipyard - David Larsen
Ideal Basic Industries - Ron Wallis
Earle M. Jorgensen Co. - Jack Bunt
Kenworth Truck Co. - Rusty Wailes
Lockheed Shipbuilding, Inc. - J. B. Quinn
Manson Construction and Engineering - Lester Hillis
Monsanto Company - Mel Miller
Northwestern Glass - Frank Glinka
Todd Pacific Shipyards Corp. - Jim Anderson
Marine Power and Equipment Co. - Dave Green
Chemical Processors, Inc. - Mike Keller
Shell - Mr. Clarkson
ARCO Petroleum - Doug Polen
Wycoff - Mel Brown
GATX Tank Storage Terminals - D.E. Miller
Rabanco - Steve Banchero

ATTACHMENT D

GROUND WATER DATA AVAILABILITY FROM PRIVATE COMPANIES

Name of Company/ Facility	Data Exists & Available	Data Exists but Unavailable	Data Doesn't Exist
Advance Electroplating			X
Bethlehem Steel	No response to letters or calls as of 3/22/85		
Boeing/Isaacson	X		
Constructors Pamco			X
Duwamish Shipyard			X
Ideal Basic Industries			X
Earle M. Jorgensen			X
Kenworth Truck	X*		
Lockheed Shipbuilding	X*		
Manson Construction			X
Monsanto	X*		
Northwestern Glass	X*		
Todd Pacific Shipyards			X
Marine Power and Equipment			X
Chemical Processors	X		
Shell	No response to letters or calls as of 3/22/85		
ARCO	X**		
Wyckoff		X	
GATX Tank Storage			X
Rabanco			X
Seattle City Light	X***		
Northwest Cooperage			X
Seattle Iron & Metals			X
Sternhoff Metals			X
Lone Star Industries	X*		
Chevron USA	X		

* Available data consists of boring logs only

** Available data very limited nature

*** Available data consists of soil testing only

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APPENDIX D

DUWAMISH GROUND WATER STUDIES
WASTE DISPOSAL PRACTICES AND
DREDGE AND FILL HISTORY

Prepared for:

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Prepared by:

Harper-Owes

March 1985

CARG007100
SEA141021

DUWAMISH GROUND WATER STUDIES

WASTE DISPOSAL PRACTICES

AND DREDGE AND FILL HISTORY

SCOPE OF WORK

This report presents a review of historical waste disposal and dredge/fill practices in the Duwamish River area. The emphasis of the review has been placed on identifying potential sources of contamination to the Duwamish area ground water. The scope of work for this review does not include information on direct waste discharges into the Duwamish River, but concentrates on waste disposal and dredge/fill practices which may affect ground water quality.

WASTE DISPOSAL PRACTICES

Information Sources

Information for the review of waste disposal practices has been obtained from the following sources:

1. Aerial Photography Analysis of Hazardous Waste Sites, Duwamish Valley, Washington. United States Environmental Protection Agency, Las Vegas, 1982.

2. An Investigation of Pollution in the Green-Duwamish River. Pollution Control Commission, Technical Bulletin 20, 1955.

3. Municipality of Metropolitan Seattle Industrial Waste Section files.

4. Washington State Department of Ecology NPDES and Hazardous Waste Files (includes Pollution Control Commission Reports).

5. Remedial Action Master Plan, Harbor Island, USEPA Hazardous Site Control Division.

6. USEPA Hazardous Waste Files

7. Photographic Analysis of Reichold Waste Site, Seattle, USEPA, Las Vegas, 1981.

8. Water Quality Assessment of the Duwamish Estuary, Washington. Harper-Owes for Municipality of Metropolitan Seattle. Seattle, 1983.

9. Abandoned Landfill Study in the City of Seattle, Seattle-King County Department of Health, Seattle, 1984.

Waste Disposal Practices

Identified waste disposal sites and unidentified potential sites are listed by location proceeding from the north to the south. Dates listed refer to the year when the site was documented. Reference numbers refer to the information sources listed above. Site locations can be found in Figures 1 through 3.

1. **Wyckoff; Reference Nos. 3, 4**

   Wyckoff generates and stores the following sludges on site: pentachlorophenal sludge, copper arsenate sludge and creosote sludge. Oily seepage into the intertidal area surrounding the plant is evident. Detailed information from USEPA files on Wyckoff is presently not available because of pending litigation and enforcement action and will become available after March 1985.

2. **(1961) N47 35.2' - W122 21'; Reference No. 1**

   This site was used as a liquid disposal area. Aerial photography showed a pool of dark-toned liquid in the middle of the site. By 1968, this site was developed into a transshipment point and the site covered by railroad facilities.

3. **(1940) N47 34.9' - W122 19.75'; Reference No. 1**

   This was a general dump site which did not appear to be associated with any local industry. Aerial photography from 1961 shows that the site was covered over by industrial development.

4. **Quemetco (Sea Fab Metals) (1975); Reference Nos. 3, 4, 5**

   A seepage pond was used by Quemetco for disposal of their process wastewater including spent chemicals, battery acid solution and most of yard

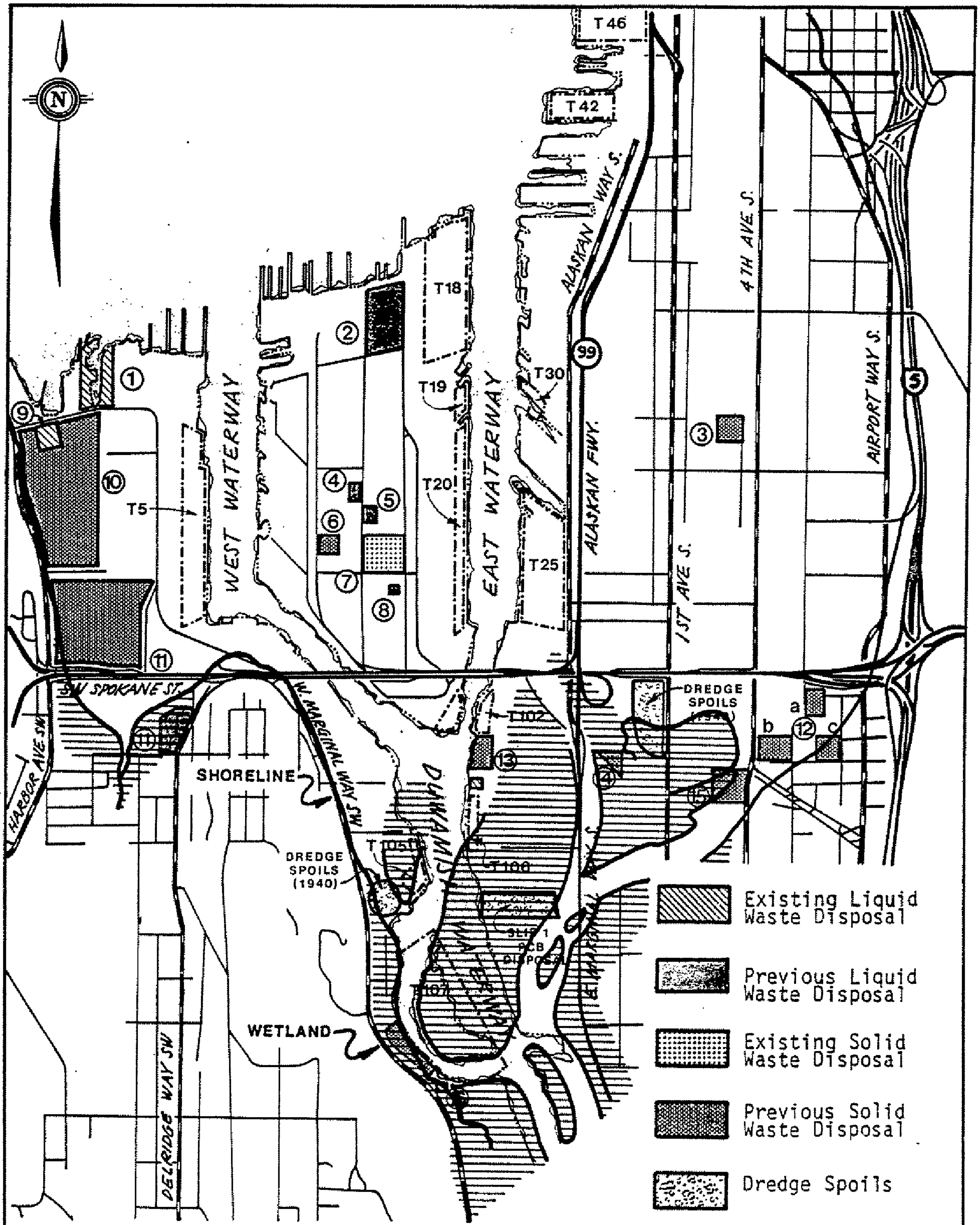

FIGURE 1:
Waste Disposal and Dredge and Fill Sites - Duwamish River
1854 SHORELINE

Adapted from Bortleson, et al., 1980

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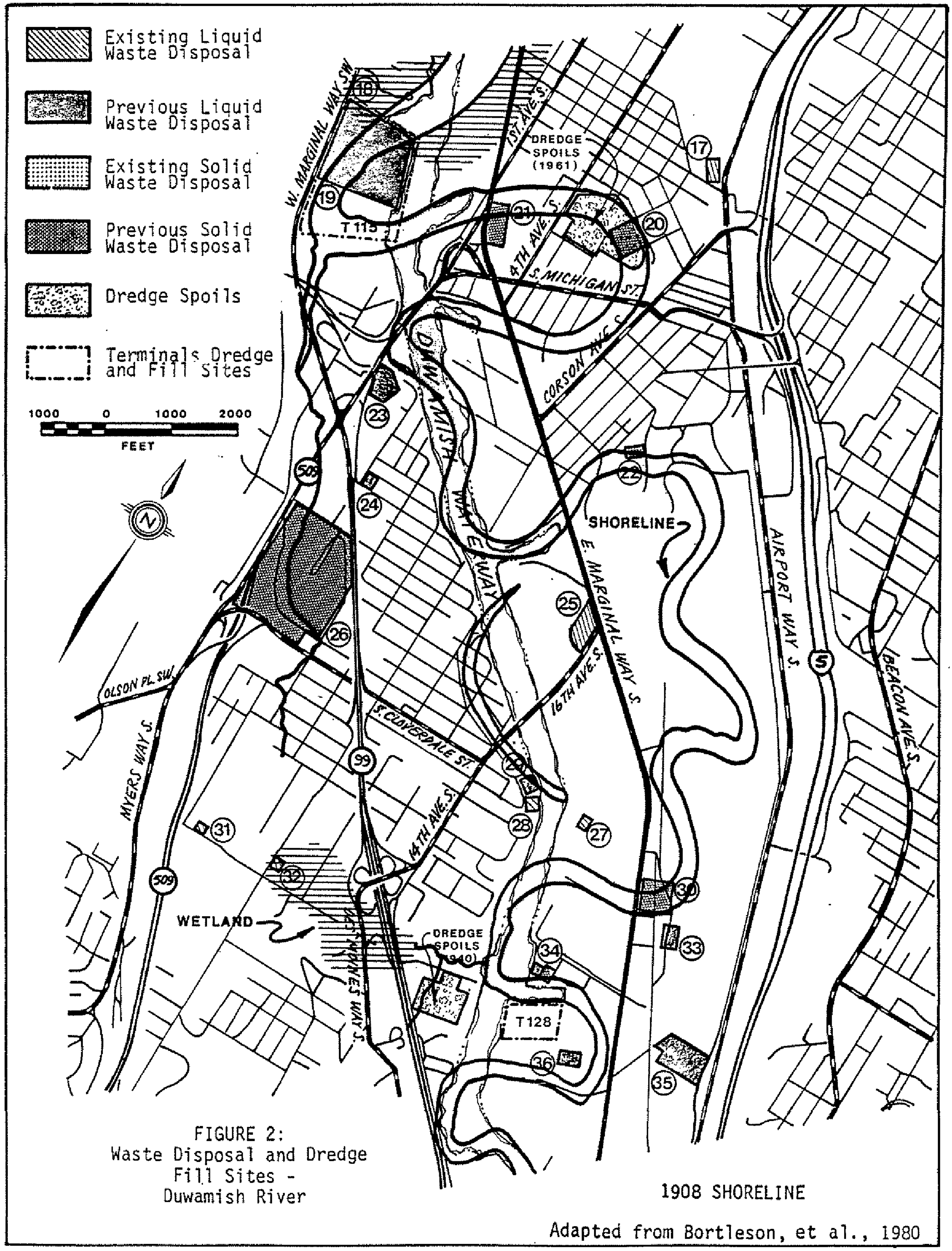

FIGURE 2:
Waste Disposal and Dredge Fill Sites - Duwamish River

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SEA141025

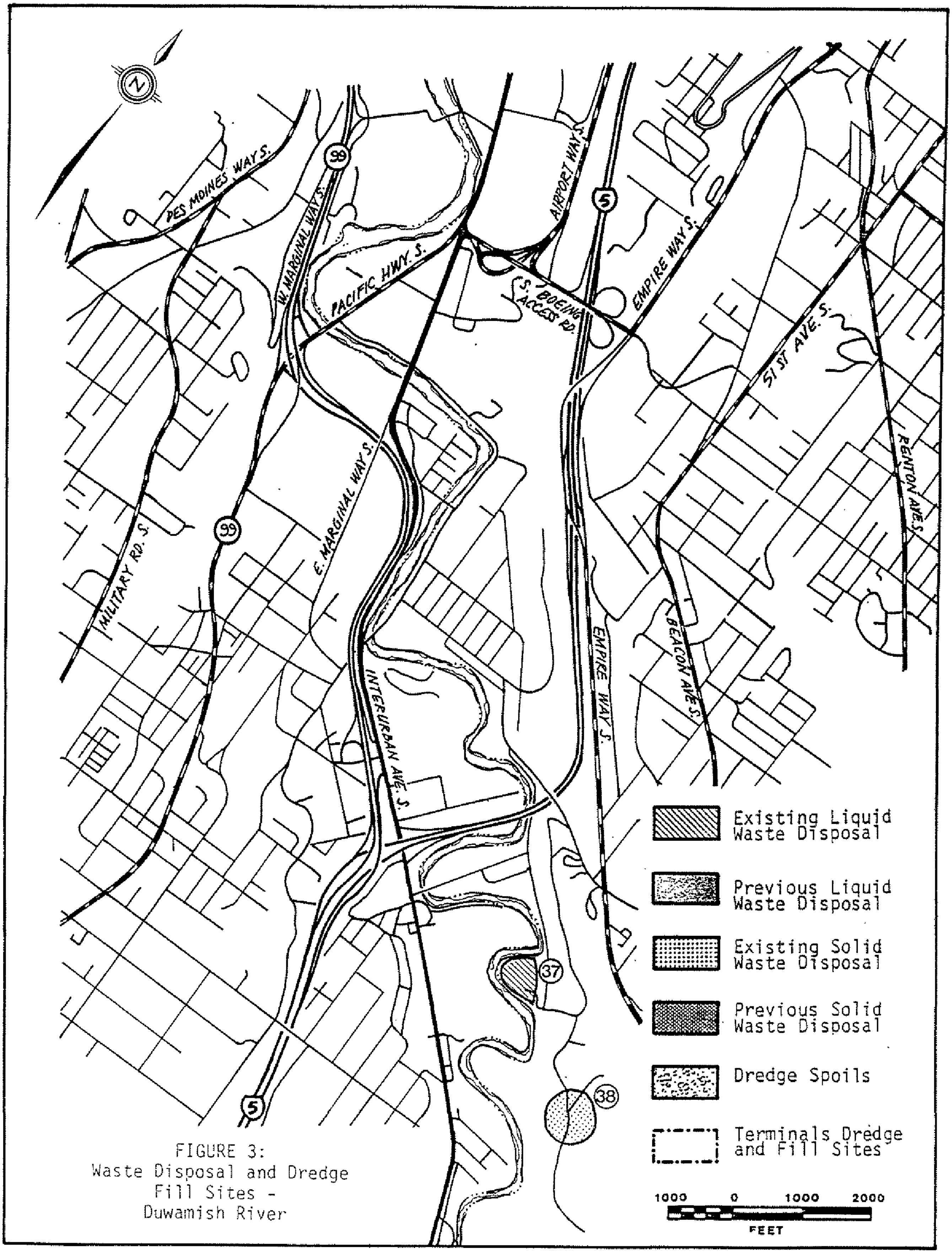

FIGURE 3:
Waste Disposal and Dredge
Fill Sites -
Duwamish River

drainage from 1975 until January 1982. The seepage pond was part of a treatment system consisting of ammonia neutralization, vacuum filtration and final disposal in the seepage pond.

Characterization of Quemetco's process waste water is given in Table 1. Water samples were collected from the seepage pond where wastewater had received prior neutralization and vacuum filtration. In 1970, it was reported that 25 gpm of wastewater was discharged. It was also reported that sludge was removed twice per year.

Prior to 1975, wastewater was discharged directly to an impoundment without pretreatment. 1974 aerial photography indicates that this impoundment was in the same location as the seepage pit. The pond was located just off 13th Avenue Southwest.

In 1983, the lagoon was bypassed and a monitoring well was installed on Quemetco's property as part of the RCRA-enforced cleanup of the seepage lagoon. Quemetco also has open storage of old batteries on site and two types of waste piles. The waste piles contained Diatomaceous earth and rubber chips and were removed during the summer of 1984. The lagoon and waste piles have been classified as a hazardous waste site under the Superfund Program and the company (Sea Fab) has recently submitted a plan for closure of the facility to the Department of Ecology. This plan be obtained from DOE.

5. **Golden Penn Oil Company, 2937-13th Avenue Southwest; Reference No. 4**

Golden Penn Oil Company was a waste solvent recycler. There is a possibility that a sludge lagoon was located at this site and that hazardous wastes were handled along with the waste solvents.

TABLE 1. Quemetco Process Wastewater Quality Data

Date	Sample Time Period	Contaminant Concentration (mg/l) Cadmium Avg.	Cadmium Peak	Chromium Avg.	Chromium Peak	Copper Avg.	Copper Peak	Nickel Avg.	Nickel Peak	Lead Avg.	Lead Peak	Zinc Avg.	Zinc Peak	Comments
10/6/76	0000 to 2245	0.15	0.58	0.01	0.02	0.94	13.0	0.45	0.79	1.0	4.1	1.0	1.9	Discharge to leach pit
11/10/77	0000 to 1630	0.30	--	0.06	--	1.2	1.5	0.48	--	3.6	5.6	1.3	1.9	Discharge to leach pit
11/11/77	0330 to 0830	NS	NS	NS	NS	1.3	1.4	NS	NS	5.7	7.0	1.2	1.3	Discharge to leach pit
2/21/78	1430	NS	NS	NS	NS	0.18	--	NS	NS	3.6	--	0.26	--	Discharge to leach pit
6/13/79	1120 to 1620	NS	NS	NS	NS	1.0	2.2	NS	NS	0.15	0.30	0.33	0.93	Discharge to leach pit
6/14/79	0020 to 0920	0.95	--	0.04	--	3.8	8.4	0.49	--	3.1	4.9	3.4	6.9	Discharge to leach pit
7/12/79	0000 to 2000	1.0	--	0.02	--	1.6	--	0.59	0.73	0.75	1.3	0.57	--	Discharge to leach pit
7/13/79	0300 to 0900	NS	NS	NS	NS	NS	NS	1.2	1.7	0.64	1.8	NS	NS	Discharge to leach pit
10/28/80	0000 to 2245	1.0	1.5	0.09	--	3.4	4.9	0.16	--	3.3	5.9	3.5	5.5	Discharge to leach pit
6/2/81	1530 to 2230	0.96	1.1	<0.04	<0.04	2.3	3.2	0.56	0.64	2.3	4.1	0.81	0.98	Discharge to leach pit
6/3/81	0930	<0.01	--	<0.04	--	<0.02	--	0.02	--	0.04	--	<0.01	--	Discharge to leach pit
7/22/81	1600	0.07	--	0.02	--	1.0	--	0.39	--	0.88	--	1.3	--	Discharge to leach pit
10/22/81	0000	2.1	--	0.06	--	4.0	--	1.1	--	4.4	--	0.79	--	Discharge to leach pit
11/24/81	1015 to 2215	1.7	2.0	<0.02	<0.02	2.8	7.6	1.1	1.3	3.4	7.1	3.0	5.8	Discharge to leach pit
11/25/81	0121 to 0921	1.0	1.2	<0.02	<0.02	4.7	7.4	0.55	0.61	2.7	4.6	1.0	1.1	Discharge to leach pit

TABLE 1. **Quemetco Process Wastewater Quality Data**
(continued)

Date	Sample Time Period	Cadmium Avg.	Cadmium Peak	Chromium Avg.	Chromium Peak	Copper Avg.	Copper Peak	Nickel Avg.	Nickel Peak	Lead Avg.	Lead Peak	Zinc Avg.	Zinc Peak	Comments
		Contaminant Concentration (mg/l)												
12/31/81	0000	-- Samples Not Analyzed --												
2/10/82	1140	2.2	--	0.02	--	7.1	--	0.63	--	0.49	--	0.55	--	Discharge to leach pit
5/26/82	1221 to 1921	0.9	1.1	0.02	0.02	1.6	3.4	0.5	0.6	6.8	15.0	1.6	2.1	Discharge to sanitary sewer
9/7/82	1000 to 2200	3.1	8.1	0.03	0.04	5.4	13.0	1.4	3.2	0.69	1.5	1.3	5.9	Discharge to sanitary sewer
9/8/82	0200 to 0900	0.13	0.17	<0.02	<0.02	<0.24	0.32	0.10	0.12	0.11	0.14	0.07	0.08	Discharge to sanitary sewer

Source: Letter from Denise Healy, Industrial Waste Investigator, Water Quality Division, Municipality of Metropolitan Seattle to Joan McNamee, Toxic Substance Control Branch, U.S. EPA, Region X, dated August 10, 1983.

Notes: NS = Not Sampled.
Available data have been numerically averaged and summarized. Only the average and peak concentrations are shown for the contaminants measured. Samples were generally collected at regular intervals throughout the sampling period, making weighted averages unecessary.

6. **(1940) N47 34.6' - W122 21.2'; Reference No. 1**

This was a small industrial facility with waste dumping located on a wetlands area. Piles of white material were located on the site. Aerial photography from 1961 shows that the area has been developed and the dumping location covered over.

7. **Seattle Iron and Metal, 2955-11th Avenue Southwest, Harbor Island; Reference Nos. 3, 4**

Wastewater at Seattle Iron and Metal is produced from the copper wire wash area. Wire which has been burned to remove the insulation is washed in a non-enclosure area and the water drains into a pit used for settling. The pit also accepts stormwater and overflows into the storm drain system. The results of washwater samples tested in 1974, 1984 and 1985 can be found in Table 2.

TABLE 2. Washwater Sample From Seattle Iron and Metal

Year:	1974	1984	1984	1985	1985
Location:	Drain	Pit	Drain	Drain	Drain
Copper, mg/L	0.760	1600	248	18.2	16.2
Lead, mg/L	0.800	74	62	11.5	4.25
Zinc, mg/L	0.440	21.9	12.5	1.19	1.41
Nickel, mg/L	0.140	.73	0.3	<0.2	<0.2
Cadmium, mg/L	---	0.156	0.105	<0.4	<0.4
Chromium, mg/L	---	0.60	0.25	<0.2	<0.2

The site also contains an unpaved scrap iron storage area where rainwater collects and seeps into the ground. The site is lower than the surrounding streets and runoff drains into the facility.

8. **Value Plating and Metal Polishing, 3207-11th Avenue Southwest; Reference No. 3**

Value opened in 1970 and discharged wastewater onto the ground behind their shop until they were connected to the sewer in 1978. Metals concentrations of their waste discharged to Metro's sewers are listed in Table 3.

TABLE 3. Wastewater Sample From Value Plating and Metal Polishing

Parameter	Concentration (mg/l)
Cadmium	0.23
Chromium	95
Copper	55
Nickel	209
Lead	0.42
Zinc	6.3

Value also stores chemical drums on unpaved ground behind their shops. Acid drippings from their processes fall onto unpaved ground and flow into a poorly maintained concrete sump.

9. **Purdy Company, 2929 S.W. Florida, Reference No. 3**

The Purdy Company operates a metal recycling yard and has handled PCB transformers. Waste automotive and machinery oil including PCB oil is spilled onto the ground. Results from storm drain sediment sample collected immediately in front of the facility will be available after March 1985.

10. **City of Seattle Landfill, Reference Nos. 4, 9**

This site, known as the West Hanford Street fill site, was a City of Seattle operated landfill which enabled the filling of the Seattle tidelands. The original fill area extended near City View Street and north to West Hanford. More recent boundaries were Harbor Avenue Southwest on the west, the railroad tracks on the east, West Hanford Street on the south and Southwest

Florida Street on the north. The site was over 20 acres in size and operated from about 1939 to 1966. Land owners included King County and Bethlehem Steel.

The site was used primarily for disposal of garbage collected by the City contract garbage collectors, but also likely contains industrial solid waste from nearby industries. The Seattle-King County Department of Public Health reports that steel mill wastes and fertilizer plant wastes were deposited on the site. In the 1940's, it is reported that hog fuel and sawdust were used as cover material. The site has also been used for the disposal of dredge material.

In 1965, the Seattle Fire Department used a 500 square feet area of the landfill for their oil fire control school. The operation lasted about three months and was located on Harbor Avenue Southwest and Southwest Lander.

The landfill operation converted a portion of the Duwamish tideflats to a large area of the Seattle Port Commission's Industrial and Harbor Development District. Longfellow Creek ran through the landfill area and was diverted into a culvert in the early 1960's. The site is also known for its high water table which underlies and/or permeates the fill. Presently, the Purdy Company, a recycler of industrial metals, occupies the northern portion of the landfill area.

11. **Bethlehem Steel Company, 8501 E. Marginal Way (1955); Reference Nos. 2, 3, 4, 6**

Bethlehem Steel Company fabricates and galvanizes steel. Sulphuric acid pickling liquor wastes were disposed of on land at the slag dump as early as 1955. Wastewater deposited on site included electroplate, hot dip and coil pickle processes.

Treatment of contact cooling water consisted of primary settling in scale settling pits, gravity oil separation and final holding in a pond for reuse at the plant. Solids were removed from the settling basin on a regular basis and deposited at the slag dump located on Southwest Andover, between 28th Southwest and 26th Southwest.

The slag dump was operated for about 20 years and contains about a four foot depth of waste material. The facility was also operated as a waste storage pile for flame trap sludge in the 1970's.

The facility closed in 1983 and Bethlehem Steel has submitted a closure plan to the EPA which recommends the removal of the contaminated slag and soils at the disposal site. Bethlehem Steel and Applied Geotechnology, Inc. are also due to soon release a Ground Water Monitoring Summary Report on the effects of the disposal site on the upper aquifer.

Early ground water monitoring results from 1982 are presented in Table 4. The EPA reports that these results must be evaluated with care because tidal effects in the area distort typical down gradient contaminant migration patterns.

12.a,b,c. **(1940) N47 34.15' - W122 19.6'; Reference Nos. 1, 9**

These sites were part of the City of Seattle general refuse dumps. By 1968, sites A and B were covered by commercial development. Site 12(C) is still in service as an auto wrecking site.

Soil explorations conducted in 1962 noted that the garbage fill at the site was underlain by soft clay. The soil borings indicated garbage fill extended approximately 11 feet. Below the garbage layer a layer of mixed soil and garbage extended an additional two feet. Ground water was found at a depth of eight feet, which coincides with the garbage layer.

The site received general refuse, dredge material and also served as the Industrial District Dump. In the early 1950's, a City Light facility was located adjacent to the site and included a pole yard and a storage area for old transformers. Excess transformers and a variety of wastes are reported to have been deposited at the south end of the fill.

13. **Ash Grove Cement (Lone Star), 3801 E. Marginal Way South; Reference No. 3**

All stormwater and wastewater generated at the Ash Grove site is diverted to an unlined surge pond located on the bank of the river. There is no surface discharge from this pond as the water is reused in their processes. Result of a water sample analysis from the pond is listed in Table 5.

TABLE 4. Ground Water Monitoring Results from Bethlehem Steel Site

Parameter	Up Gradient test well	Down Gradient test well
Cadmium (mg/l)	0.016	0.024
Chromium (mg/l)	0.20	0.05
Lead (mg/l)	0.52	0.51

TABLE 5. Ash Grove Cement Surge Pond Water Analysis

Parameter	Concentration
pH	10.8
Copper (mg/l)	0.1
Zinc (mg/l)	0.13
Iron (mg/l)	2.3
Chromium (mg/l)	0.35
Lead (mg/l)	0.56
Conductivity (umhos)	225
Hardness (mg/l)	120

Prior to 1985, a variety of materials was stored on-site at Ash Grove cement on unpaved areas. Ash Grove buys 25,000 tons of Asarco slag per year, which was stockpiled outside, uncovered. Coal fly ash was also stored outside, uncovered. These piles were removed and are presently stored indoors.

Coal is stored outside in coal pits which are partially covered with black plastic tarps. Oil diesel and lubricants are stored in drums and tanks on a concrete platform surrounded by an unpaved area where spillage can seep into the ground. Ash Grove has also deposited brick, concrete, waste cement and dust in a landfill adjacent to the river.

14. **(1961) N47 34.1' - W122 20.15'; Reference No. 1**

This site is located adjacent to the Puget Sound Fabricators facility and contains several piles of white-toned waste material.

15.a. **Seattle City Light Substation (1961) N47 34.05' - W122 20.15'; Reference Nos. 1, 3**

This site was used as a dump area for trash and other waste material and is located just south of the Duwamish substation. By 1968, this site was covered by commercial development.

The Duwamish substation drainage systems contain gravel oil retention sumps which collect transformer area runoff before being pumped directly to the Duwamish. The two transformers at this station are not PCB transformers.

Drainage from the capacitor banks at the substation drains directly onto the soil. All of the capacitors in these banks are PCB equipment.

15.b. **Seattle City Light Georgetown Steamplant; Reference No. 3**

The Georgetown steamplant was last operated in November 1974. SCL representatives state that no PCB equipment has ever been used at this site.

The storm water pond located at the southwest corner of City Light's property was found to contain 500 mg/kg PCB in a composite sediment sample. The pond receives flows from Seattle City Light property and from the King County Airport (Boeing Field). PCB's have also been found in the North Fire pits of Boeing field, which drain into the pond, but at much lower concentrations. Seattle City Light is conducting an investigation of the PCB sources which is scheduled for completion in February 1985.

A small dumpsite was also located just north of the pond and may have received waste oils. The dump site was closed and cleaned up in 1983 and does not appear to be a PCB source.

16. **Ideal Cement Company, 5400 W. Marginal Way Southwest; Reference No. 4**

Kiln and truck washdown water are disposed of in a soaking pit/settling pond. There is also a flue dust fill site located on West Marginal Way South and South Hudson.

17. **Chempro (1980) N47 33.25' - W122 19.3'; Reference No. 1**

Chempro recycles waste solvents. Analysis of 1980 color photography reveals that this site contained numerous 55 gallon drums, most of which were stored on a concrete pad at the north end of the site. Solvents are also stored in several underground tanks. A ground water monitoring study of the Chempro site was conducted by Harper-Owes in 1984 for Chempro and has not been released by the industry.

18. **MRI (MST Chemicals), 6000 West Marginal Way Southwest; Reference Nos. 3, 4**

MRI was constructed in 1963 and processes tin plate scrap. The company operated two evaporation/seepage lagoons for disposal of its wastewater until 1976 when they connected to the Metro sewer system. The lagoons were unlined basins of six foot depth into which about 3500 gallons per week were discharged. In 1969, the waste was reported as containing a pH of 11; 25,000 mg/l NaOH; 50,000 mg/l alkalinity; and 200 to 500 mg/l Na_2SnO_3. The waste also contained high COD and BOD.

Sludge from the lagoon is reported to have been removed periodically. The present quality of wastewater inputs to Metro's sewer from MRI can be found in Table 6.

TABLE 6. 1981 MRI Wastewater Quality Analysis

Parameter	Concentration (mg/l)
Aluminum	83
Antimony	4.1
Arsenic	0.26
Zinc	3.0
Thallium	0.87
Nickel	1.3
Lead	3.6
Iron	110
Cadmium	0.20

19. **Reichold Chemical Company, 5900 West Marginal Way; Reference Nos. 1, 2, 7**

The Reichold plant manufactured synthetic resins, formaldehyde, pentachlorophenols and hydrochloric acid. Highly toxic wastewater was discharged directly into the river until the summer of 1955 when corrective action was taken by the industry in the form of temporary settling basins for the wastewater. EPA files indicate that the plant was closed in 1958.

Aerial photography taken in 1960, 1961 and 1970 show three wastewater disposal pits contained by earthen dikes at the Reichold site. The site occupied approximately 15 acres. By 1970, a major dike had been constructed to separate the area from the river and the process of filling behind the dike had commenced. By 1974 the entire site was filled and paved over and now serves as a transshipment area.

20. **(1940) N47 32.95' - W122 19.45'; Reference No. 1**

This site was a possible waste pit containing white-toned material. By 1961, the site was covered by fill material and by 1968, commercially and industrially developed.

21. **(1940) N47 32.8' - W122 19.9'; Reference No. 1**

This site consisted of two small dump areas. The site was covered by industrial development in 1961.

22. **(1940) N47 32.5' - W122 19.0'; Reference No. 1**

This site was a small dump probably associated with a nearby industry. By 1961, the site was covered by commercial development associated with King County International Airport.

23. **Northwest Cooperage Company, 7152 First Avenue South (1961); Reference Nos. 1, 2**

Northwest Cooperage Company reconditions and repaints old barrels and drums. Aerial photography from 1961, 1968 and 1974 shows several thousand drums stored throughout the site. 1980 color photography reveals ground stains indicating past spills.

24. **Liquid Air Company, 7560 Second Avenue South; Reference No. 4**

Wastewater from acetylene production was disposed of in ponds up until 1979. The ponds were excavated and filled by 1984.

25. **AirCo (1940), 7700 14th Avenue South; Reference No. 1**

This industry had two pits containing white acetylene waste material. Most of the site had been developed into a parking lot by 1961. At the north end of the site, a two acre triangular pit of 10-15 feet depth still exists and receives carbide residue from acetylene manufacture. Calcium carbonate is also stockpiled on-site.

26. **(1940) N47 31.75' - W122 19.8'; Reference No. 1**

In 1940, this site was the local garbage dump. Aerial photography indicates a wide variety of waste material.

From 1945 to 1966, the site was expanded and developed into The South Park Landfill and operated as a burning dump by the City of Seattle until 1962. A portion of the area served as an auto junkyard. Two liquid waste disposal ponds were located on the site. One contained a light-toned liquid with black material on the surface, the other a dark-toned liquid.

In 1966, some of the area had been covered over and solid waste transfer station buildings were constructed over the old burn dump. The disposal ponds were no longer present and new dumping areas were developed within the greater site.

By 1974, several additional buildings were developed on the site and covered the old auto junkyard areas. A storage yard also covered part of the site in 1974 and by 1980, all the dump areas had been developed.

The site is reported to have received many types of waste including industrial waste generated in the adjacent industrial area. Seattle-King County Department of Public Health reports that personal recollections by commercial haulers state that "lots of toxics" went to South Park.

In February 1983, three soil borings were completed at the site. The borings showed that subsurface soils at the site consisted of fill over sand. The fill material was 10 feet thick and consisted of a loose, silty, gravelly sand with numerous brick, glass fragments and scattered organics. The underlying sand was oil coated and extended to a depth of 22 feet. Ground water levels at the time of drilling and two weeks after varied from 10 to 13 feet below the existing ground surface.

27. **Jorgensen Steel, 8531 E. Marginal Way South; Reference No. 3**

Jorgensen Steel employed an acid house for etching machine parts, which contained three tanks - two filled with 50 percent muriatic acid and the third with rinse water. The tanks drained into a concrete walled pit with a dirt bottom which was filled with limestone rocks. Analysis results of the solutions in each tank and the soils in the limestone pit can be found in Table 7. The pit was closed in March 1984.

Jorgensen Steel also operates a laydown yard for storage of metal scrap. The yard is unpaved and contains piles of uncovered scrap material.

28. **Malarkey Asphalt, 8700 Dallas Avenue South; Reference No. 3**

Malarkey Asphalt manufactures asphalt and roofing tar. There is an unlined wastewater disposal pond on the bank of the river which occasionally overflows into the Duwamish. Metro has recently collected a sample from the pond and results will be available after March 1985.

29. **A and B Barrel Company, 8604 Dallas Avenue (1955); Reference No. 2**

previous contents of barrels

In the reconditioning and repainting of used barrels and drums, the A and B Barrel Company used about one ton per month of sodium hydroxide as a cleaning agent. Liquid waste, including oils, grease and sodium hydroxide, were discharged into a small pond which overflowed directly into the Duwamish. Wastewater concentrations contained 940 mg/l NaOH.

30. **(1940) N47 31.5' - W122 17.9'; Reference No. 1**

This site was a small industry with a stockpile of white material. The stockpile was reduced by 1961 and the site covered by parking lots by 1968.

31. **Ace Galvanizing, 429 South 96th; Reference Nos. 4, 8**

Ace Galvanizing discharges into a yard catch basin which flows into a storm water collection ditch. Water samples collected in the ditch contained total metals concentrations up to 0.02 mg/l Cd; 0.92 mg/l Cr; 0.74 mg/l Cu; 6.8 mg/l Ni; 1.7 mg/l Pb; and 250 mg/l Zn. Zinc slag is also stored on-site.

32. **Advance Electroplating, 9585 8th Avenue South; Reference Nos. 4,8**

Advance discharges rinsewater from chromium, copper, cadmium and nickel electroplation and galvanizing processes into a neutralizing pit which overflows directly into the storm drain. Discharge concentrations of zinc and nickel were measured at 9.30 mg/l Zn and 2.20 mg/l Ni.

33. **Kenworth Truck Company, 8801 East Marginal Way (1955); Reference No. 2**

Aluminum deoxidizing tank wastewater from Kenworth was disposed of on land approximately 2000 feet from the river. The waste is presently being transported off the site.

34. **Monsanto (1961); Reference Nos. 1, 4**

Monsanto manufactures vanillin and has also manufactured resins in the past. Monsanto currently disposes of its Vanillin Black Liquor Solids (VBLS) at the Cedar Hills Landfill. VBLS leachate measured at Cedar Hills has high COD (approximately 20,000 mg/l) and high copper concentrations (300 mg/l).

TABLE 7. **Analysis of Jorgensen Steel Etching Tank Solutions and Pit Core Samples**

	West tank etching solution (mg/l)	Middle tank etching solution (mg/l)	Rinse tank solution (mg/l)	Limestone core pit (mg/kg)
Total cadmium	.54	L/0.02	L/0.02	L/0.02
Total chromium	600.	920.	7.2	150.
Total nickel	840.	1100.	24.	38.
Total zinc	7.6	24.	1.2	36.
Total copper	230.	190.	5.3	42.
Total iron	20,000.	39,000.	430.	14,000.
Total lead	2.5	8.7	L/0.2	L/20.
Total selenium	0.8	L/0.2	L/0.2	L/20.
Total calcium	65.	140.	22.	---
Total magnesium	130.	230.	4.8	---
Total calcium and magnesium calc. as hardness (CaCO3)	710.	1,500.	74.	---
Water soluble calcium	---	---	---	50.
Water soluble magnesium	---	---	---	1.7
Water soluble calcium calc. as CaCO3	---	---	---	130.
EP Toxicity				
Arsenic	1.6	L/0.2	.2	.4
Barium	L/0.5	L/0.5	L/0.5	L/0.5
Cadmium	.53	L/0.02	L/0.02	L/0.02
Chromium	600.	920.	7.2	L/0.1
Lead	2.5	8.7	L/0.2	L/0.2
Mercury	L/0.005	L/0.005	L/0.005	L/0.005
Selenium	.5	L/0.2	L/0.2	L/0.2
Silver	L/0.1	L/0.1	L/0.1	L/0.1

L/indicates 'less than'.

Monsanto operated a landfill from approximately 1945 to 1955 at the present Kenworth Truck site. The landfill site is now covered by a parking lot and is well drained. Company representatives claim that only reactor vessel scale was deposited in the landfill and that the scale contained only calcium and sodium carbonate contaminated by about 2% copper. Approximately 200 tons of scale were deposited at the landfill.

Aerial photography from 1961 also shows that several uncontained storage/processing tanks and a wastewater disposal pit were located on the site. By 1974, additional contained storage/processing tanks have replaced the uncontained tanks and wastewater disposal pit.

35. **(1940) N47 31.1' - W122 17.6'; Reference No. 1**

This was the site of a petroleum distributor. All tanks were contained, but aerial photography indicates past spills. This site was removed by the construction of the King County Airport extension by 1961.

36. **(1940) N47 31.05' - W122 17.95'; Reference No. 1**

This site contained at least 10 uncontained storage tanks in 1940. By 1961, the number of tanks was reduced to four, and by 1980, the tanks were removed and the site paved over.

37. **(1961) N47 28.9' - W122 15.4'; Reference No. 1**

This small industrial facility had on-site storage/processing tanks which were uncontained. Aerial photography shows that by 1974, an uncontained horizontal storage tank has been added to the site. 1980 photographs show six additional uncontained horizontal tanks.

38. **Sunset Demolition, 13300 Empire Way South (1985); Reference No. 3**

This landfill has been receiving solid wastes from Todd Shipyard and Jorgensen Steel. The wastes deposited in the landfill include sandblasting waste from Todd, and foundry sand and/or, possibly, fly ash from Jorgensen. The runoff from the site is reported to have high levels of copper, lead and chromium. A runoff sample was collected in December 1984 and analysis of that sample should be completed by January 1985.

PETROLEUM PRODUCTS STORAGE AND SPILLS

Although accidental spillage of oil and petroleum products is not technically a waste disposal practice, several tank farms on Harbor Island and around the lower Duwamish have had major spills. Because the areas around the tanks are paved with rough gravel, any spillage will seep onto the ground around the tanks. Some of the spilled product has been recovered through ground water pumping at Chevron and Shell Oil, but much of it may still be underneath the tank farms or may have leached into the Duwamish River. Oils, solvents, lubricants and wood preservatives have been stored at the following facilities:

Atlantic Richfield, 1652 Southwest Lander, Harbor Island
Chevron, 1901 East Marginal Way South
GATX Terminals, 1733 Alaskan Way South
Mobil Oil, 1711 - 13th Southwest, Harbor Island
Shell Oil, 2720 - 13th Southwest, Harbor Island
Texaco, 2555 - 13th Southwest, Harbor Island

The Washington Department of Ecology has records of some of these spills at some of these facilities.

DREDGE AND FILL HISTORY

INTRODUCTION

The following sections describe the historical shoreline changes and current dredge and fill practices in the Duwamish River. Most of the major dredge and fill operations occurred in the early 1900's. More recent dredge and fill operations have been generally limited to maintenance dredging of the main channel and terminals, and filling for construction and expansion of terminals.

The U.S. Army Corps of Engineers regulates the dredge and fill operations in the Duwamish River and has kept records of these operations since 1965. Prior to 1965, only limited information, such as historical maps and records, is available.

HISTORICAL SHORELINE AND WETLAND CHANGES

Bortleson, et. al. conducted a detailed investigation of the Duwamish River historical features and reported the following:

> "The shoreline and wetland environment of the Duwamish River delta has changed dramatically in the past 125 years. The most notable changes since the earliest surveys are the massive landfill of the intertidal reach of Elliott Bay and the channelization of the Duwamish River.
>
> In 1854, the Duwamish River meandered across its valley and entered Elliott Bay through three main distributary channels. A broad intertidal area extended bayward beyond marshlands near the river mouth to near the northern edge of the present-day Harbor Island. Smaller areas of wetland were located in an embayment southwest of the West Waterway, east of the small peninsula of land that was early Seattle.
>
> In 1895, the filling of the marsh and intertidal area began with the dredging of the East Waterway. Material dredged from the East Waterway was deposited as fill over a wide area of what today is Harbor Island. From 1901 to 1904, several thousand cubic meters of material were removed from Beacon Hill to the intertidal area by hydraulic sluices. By 1917, the East and West Waterways had been formed and more than 5.7 sq km (2.2 sq mi) of intertidal area had been filled, largely by deposition of dredge spoil from the two water ways which flanked it. All the former

> marsh except a small area on the northern tip of Kellogg Island has been filled or converted to urban land use. Dredging to form the Duwamish Waterway has created a channel deeper than the former natural channel and has lengthened the landward incursion of saltwater in the channel."

Approximate locations and dates of the major changes to the Duwamish River are shown in Figure 4. The main changes to the river occurred between 1895 and 1921, with the main channel construction completed in 1918.

Filling of the old river channel was begun in 1918 and completed by approximately 1960 (see Figure 1 and 2 overlays for the old river configuration). Although the source of the fill was not documented, it can be assumed that the dredge spoils from main channel construction were used as the primary fill material. The source(s) of more recent (i.e., post 1920) channel fill is also unknown.

Unconsolidated fill deposits can contain conduits for ground water movement and special notice should be given to waste disposal sites located on fill material. (see Figures 1 and 2). This condition is evidenced by the subsiding of ground on hydraulic fill along the Duwamish River, which occurred during the 1949 and 1965 earthquakes, apparently as a result of liquification during ground shaking (USGS, 1975).

It is interesting to note that "background" alluvial sediments from the Green/Duwamish River presently contain rather high mercury concentrations (average = 7 mg/kg dry wt.), presumably from the erosion of natural mercury veins adjacent to the river in its upper reaches (Harper-Owes, 1983). River-derived fill material may also contain similar levels of this metal, though previous sediment inputs from other river systems which have since been diverted out of the Duwamish (the White and Black Rivers in 1906 and 1916, respectively) may have diluted this concentration considerably.

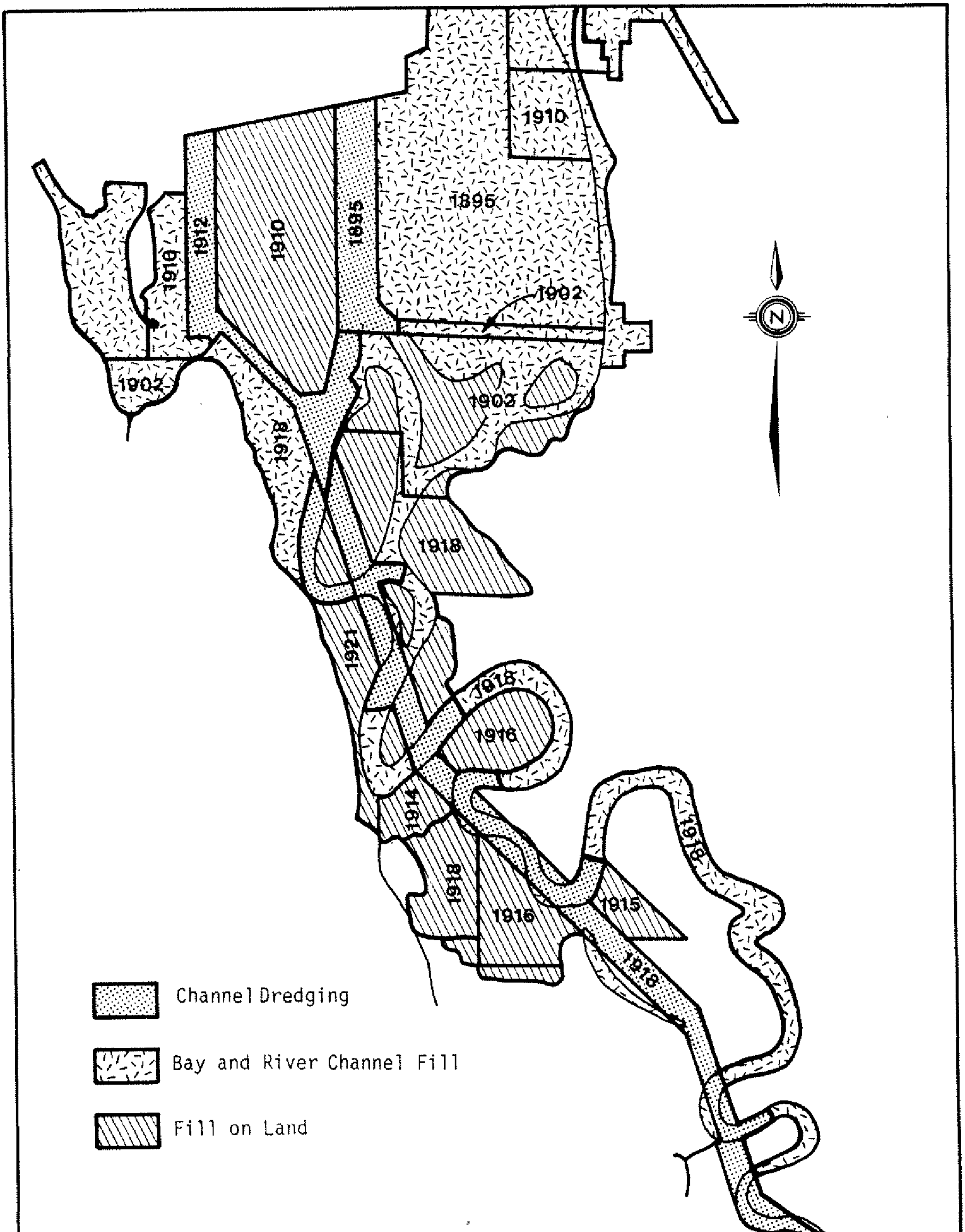

FIGURE 4: Major Dredge and Fill Construction of the Duwamish Waterway
(adapted from Seattle Urban Design, 1971)

DREDGE AND FILL PRACTICES

General

The U.S. Army Corps of Engineers, the Port of Seattle and private individuals and companies conduct dredging operations on portions of the Duwamish Waterway. Sediments must be periodically dredged for maintenance and construction of navigation channels, berths and terminals for deep-draft shipping in the waterway. Disposal of the dredged materials is regulated by the Corps of Engineers under Section 404 of the Clean Water Act of 1977. The Corps grants permits for the disposal of dredged materials at designated disposal sites subject to approval by the USEPA and the Washington State Department of Ecology. The EPA requires chemical testing of the materials to be dredged and determines if the material can be disposed of at the open-water disposal area in Elliott Bay (Four Mile Rock). Dredge material judged by the EPA to be too contaminated for open-water disposal is either contained and capped in shoreline fills or placed in confined upland disposal areas.

Corp of Engineers

The Corps of Engineers conducts maintenance dredging of the main channel of the Duwamish about every one or two years. A summary of the Corps' maintenance dredging of the waterway is presented in Table 8. All Corps of Engineers maintenance dredge spoils have been disposed of at Four Mile Rock.

Port of Seattle

Port of Seattle dredge and fill records are presented in Table 9. No records have been found which identify the locations of the upland disposal sites. Most upland disposal sites, however, are most likely located near the dredging site in order to minimize transportation costs.

Figures 1 through 3 show terminal disposal areas which have received dredge spoils. Some upland disposal sites have been identified from areal photography; however, the source of the dredge material is unknown.

TABLE 8. Summary of Duwamish Waterway Maintenance Dredging Quantities; 1960-1984

Maintenance Dredging (m^3/year)

Year	COE 0-92 km 1.2-4	COE 92-157 km 4-6	COE 157-223 km 6-8	COE 223-276 km 8-10
1960	-0-	-0-	36,800	188,000
1961	-0-	78,100	-0-	-0-
1962	-0-	-0-	-0-	-0-
1963	-0-	-0-	-0-	-0-
1964	6,600	41,200	192,200	413,700
1965	-0-	-0-	-0-	-0-
1966	-0-	-0-	-0-	-0-
1967	-0-	-0-	-0-	-0-
1968	6,100	74,400	49,700	314,100
1969	-0-	-0-	-0-	-0-
1970	-0-	-0-	-0-	-0-
1971	-0-	-0-	-0-	248,600
1972	-0-	-0-	-0-	-0-
1973	-0-	-0-	-0-	-0-
1974	-0-	-0-	-0-	100,700
1975	-0-	-0-	-0-	219,400
1976	-0-	-0-	44,300	215,600
1977	29,100	37,500	-0-	131,900
1978	-0-	-0-	110,400	22,900
1979	-0-	-0-	-0-	-0-
1980	-0-	-0-	-0-	157,200
1981	-0-	-0-	-0-	92,100
1982	-0-	-0-	-0-	95,600
1983	-0-	-0-	-0-	96.500
1984	840	-0-	-0-	67,300
AVERAGE	1,600	9,200	16,000	88,500

TABLE 9. Port of Seattle Dredge Record for the Duwamish Waterway

Dredge Location	Year	Dredge Quantity (m^3)	Disposal Site
Terminal 5	1969	22,100	Upland site
Terminal 5	1969	425	Terminal 5 site
Terminal 5	1971	12,700	Upland site
Terminal 18	1966	100,000	Terminal 18 fill
Terminal 18	1967	62,000	Terminal 18 fill
Terminal 18	1971	14,400	Upland site
Terminal 19	1974	85,500	Pamco Duwamish Boulevard disposal sites
Terminal 20	1971	14,400	Upland site
Terminal 20	1973	72,200	Kellogg Island
Terminal 20	1978	4,380	Terminal 42 fill site
Terminal 25	1971	8,920	Upland site
Terminal 25	1971	67,900	Not known
Terminal 25	1972	13,200	Not known
Terminal 25	1973	1,890	Four Mile Rock
Terminal 25	1978	15,900	Terminal 42 fill site
Terminal 30	1971	34,000	Upland site
Terminal 30	1978	15,900	Terminal 30 fill site
Terminal 46	1979	162,000	Terminal 30 fill
Terminal 105	1967	110,000	Upland site
Terminal 105	1967	5,090	Terminal 105 fill
Terminal 105	1978	9,770	Terminal 42 fill site
Terminal 115	1969	754,800	Terminal 115 fill
Terminal 115	1978	41,900	Terminal 42 fill site
Terminal 115	1979	16,600	Four Mile Rock
Terminal 128	1974	101,000	Four Mile Rock
Terminal 128	1974	59,600	Terminal 115 fill
Terminal 128	1974	13,800	Terminal 128 fill
Terminal 128	1975	74,200	P-2 fill

Fill material quantities deposited at Port of Seattle terminal fill sites are presented in Table 10. Table 11 qualitatively indicates the potential for elevated concentrations of heavy metals, PCB and PAH in the dredge spoils used as fill for each terminal site. The reported concentrations are based on the annual deposition-weighted values for the main channel reach adjacent to the dredged terminal (Harper-Owes, 1983). It should be noted that the actual concentrations of the terminal dredge spoils are not known. The main channel concentrations are presented only to indicate the possible order of magnitude of levels present in the dredge spoils.

Private Individuals and Companies

Several landowners along the Duwamish Waterway periodically engage in dredge and fill practices. A summary of the Corps of Engineers permits which regulate the dredge and fill activity is presented in Table 12. Most of the dredge material has been disposed of at Four Mile Rock. Again, when uplands disposal is indicated, the disposal site is unknown.

PCB Spill and Clean-up

On September 13, 1974, an electric transformer destined for arctic service was dropped and broken on the north pier of Slip 1 of the Duwamish River. As a result, PCB transformer fluid, Aroclor 1242, was discharged onto the pier and into the water. After becoming aware of the type and quantity of fluid spilled, EPA acted to determine the extent of pollution. Once determined feasible, clean-up of the fluid was attempted using several hand dredges.

Results from EPA Region X Laboratory's monitoring of this initial clean-up operation indicated only eighty of an estimated 255 gallons of PCB were recovered and the remaining fluid had begun to spread throughout the slip and into the river channel (Blazevich, et. al., 1977). Recognizing the seriousness of this problem, EPA and the Army Corps of Engineers conducted a second recovery operation to remove the remaining PCB using a hydraulic dredge.

TABLE 10. **Port of Seattle Terminals Fill Quantities**

Terminal	Quantity of Fill (m^3)	Source of Fill Material
Terminal 5	425	On-site dredging
Terminal 18	162,000	On-site dredging
Terminal 18	346	On-site material and/or dredging
Terminal 25	Not known	Not known
Terminal 30	15,900	On-site dredging
Terminal 30	162,000	Terminal 46 dredging
Terminal 30	13,000	On-site material and/or dredging
Terminal 42	4,380	Terminal 20 dredging
Terminal 42	15,900	Terminal 15 dredging
Terminal 42	9,770	Terminal 105 dredging
Terminal 42	41,900	Terminal 115 dredging
Terminal 102	Not known	Not known
Terminal 105	5,090	On-site dredging
Terminal 105*	12,000	Terminal 18/20 dredging
Terminal 106	Not known	Terminal 102 (?)
Terminal 107	54,000	Terminal 20
Terminal 107	4,000	Not known
Terminal 115	754,800	On-site dredging
Terminal 115	59,600	Terminal 128 dredging
Terminal 128	13,800	On-site dredging
Terminal 128	23,000	On-site material and/or dredging

*This disposal site is currently being investigated by the Port of Seattle to determine if the dredge spoils have resulted in significant contamination of local ground water (J. Dohrman, Port of Seattle, personal communication).

TABLE 11. **Typical Chemical Quality of Main Channel Sediments Adjacent to Construction Dredge Sites (mg/kg dry wt.)**

Dredge Location		Arsenic[a]	Cadmium[a]	Copper[a]	Mercury[a]	Lead[a]	Zinc[a]	PCB[b]	PAH[c]
	5	50	3	270	L/1	510	510	0.5	9
	18	40	3	100	L/1	150	200	1.5	6
Terminal	19	40	3	100	L/1	150	200	1.5	6
Terminal	20	40	3	100	L/1	150	200	1.5	6
Terminal	25	40	3	100	L/1	150	200	1.5	6
Terminal	30	40	3	100	L/1	150	200	1.5	6
Terminal	46	--	--	--	--	--	--	--	--
Terminal	105	30	4	80	L/1	130	310	2.5	5
Terminal	115	20	2	40	L/1	40	110	1.3	2
Terminal	128	7	2	30	7	40	100	1.3	2

[a]1972-1982
[b]1973-1977
[c]1978-1982 (PAH denotes polynuclear aromatic hydrocarbons)

TABLE 12. Private Dredge and Fill Operations Along the Duwamish Waterway

Date	Name	Work Description	Dredge Spoils Disposal
1965	Washington State Highways	Dredge	1
1965	SS Mullen, Inc. (slip 3)	Dredge and disposal, fill	1
1965	Ideal Cement	Fill	-
1966	SS Mullen, Inc.	Dredge and fill	1
1966	RC Crow	Fill	-
1967	Duwamish Shipyard	Dredge	1
1968	Monsanto	Dredge	1
1969	Boeing	Fill	-
1969	Manson Construction	Dredge and disposal	1
1969	Kaiser Cement	Dredge	1
1970	Glacier Sand and Gravel	Fill (construction rubble)	-
1970	City of Seattle S. Idaho Street	Dredge	1
1970	Monsanto	Dredge	1
1972	Northwestern Glass	Fill	-
1973	Monsanto	Dredge	1
1973	Boeing	Fill	-
1973	Boyer Towing	Dredge	1
1973	Pacific Construction	Dredge	1
1973	Hurlen Construction	Dredge	1
1973	Seaboard Lumber	Dredge	1
1974	Boulevard Excavating	Dredge and fill	1
1975	Monsanto	Dredge and disposal	1
1976	Boyer Alaska Bargelines	Dredge	1
1976	Bruce Hansen	Dredge	1
1976	Delta Marine	Dredge	1
1977	Hale and Gilmur	Dredge	1
1977	Chiyoda International	Fill	-
1977	Manson Construction	Fill	-

Table 12 (continued)

Date	Name	Work Description	Dredge Spoils Disposal
1977	AWI Sand and Gravel	Fill	-
1977	Duwamish Marina	Dredge and disposal	1
1977	Taylor, E.L.	Fill	-
1978	Pott, Tom	Fill	-
1978	Naifonov, S.A.	Fill	-
1978	Seaboard Lumber	Dredge	1
1978	Hale's Construction	Fill	-
1978	Utilities Warehouse	Fill	-
1978	Manson Construction	Dredge and fill	1
1978	Slater, Robert W.	Fill	-
1978	Ideal Cement	Maintenance dredging	Four Mile Rock
1979	Kaiser Cement	Dredge	Four Mile Rock
1979	Marine Power & Equipment	Dredge and fill	1
1980	Hurlen Construction	Dredge	Four Mile Rock
1980	Lone Starr	Dredge	mtl used in cement kilns
1981	Marine Power & Equipment	Dredge (65,000 m^3) (3 years)	Four Mile Rock
1981	Delta Marine	Dredge	Four Mile Rock
1981	Foss Alaska Line	Dredge	Four Mile Rock
1981	General Construction	Dredge	Four Mile Rock
1981	Lynden Transport	Dredge and Fill	Fill behind bulkhead & Four Mile Rock
1981	Duwamish Shipyard	Dredge (9,200 m^3)	Four Mile Rock
1981	Duwamish Shipyard	Maintenance dredging (5 years)	Four Mile Rock
1981	Marine Power & Equipment	Fill	-
1982	Hale and Gilmur 6343 First Ave. S.	Dredge (4,600 m^3)	Upland Disposal
1982	Duwamish Yacht Club	Dredge (460 m^3)	Upland Disposal
1982	Duwamish Yacht Club	Maintenance dredging	Four Mile Rock
1982	Morton Marine Equipment	Maintenance dredging (5 years)	Four Mile Rock

Table 12 (continued)

Date	Name	Work Description	Dredge Spoils Disposal
1982	General Construction	Maintenance dredging (6 years)	Four Mile Rock
1982	Western Marine Construction	Dredge	Four Mile Rock
1982	Hale and Gilmur	Fill	-
1983	Lynden Transport	Maintenance dredging (10 years)	Four Mile Rock
1983	Muckleshoot Indian tribe	Fill	-
1983	Manson Construction	Dredge (5,400 m3)	Four Mile Rock
1983	Manson Construction	Maintenance dredging (600 m^3/year-10 years)	Four Mile Rock
1984	Kaiser Cement	Maintenance dredging (10 years)	Four Mile Rock
1984	Boeing Military	Fill	-
1984	Steinman, Merle 7410 5th Ave. S.	Dredge (140 m^3)	Upland Disposal

1. Information currently not available; may be available in Corps of Engineers Archives.

The Corps of Engineers piped the contaminated sediments to a disposal site prepared on land 2,000 feet north of the slip and immediately adjacent to the river (Figure 1). All dredge spoil water from the hydraulic dredge was treated with flocculent, passed through three unlined disposal ponds and filtered through both a particle filter and an activated carbon treatment unit. Effluent water from the treatment system contained acceptably low PCB levels (<0.3 ug/l) to warrant return discharge to the Duwamish (Blazevich, et. al., 1977). Most of the PCB "treatment", however, resulted from particulate deposition within the disposal ponds, which accumulated an estimated 5,470 m^3 of sediments. The PCB concentration of these dredge spoils varied from 31 to 185 mg/kg wet weight, with the higher concentration generally occuring at sites closest to the river. The volume-weighted average concentration was estimated at 116 mg/kg as wet weight, or roughly 180 mg/kg as dry weight.

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APPENDIX E

Municipality of Metropolitan Seattle

Manual of Ground Water Sampling Procedures

MUNICIPALITY OF METROPOLITAN SEATTLE

MANUAL OF GROUND WATER SAMPLING PROCEDURES

The objects of the sampling procedures described in this manual are 1) to minimize changes in ground water chemistry during sample collection and transport to the laboratory, and 2) to maximize the probability of obtaining a representative ground water sample. A working knowledge of the chemical processes that can influence the concentration of dissolved species is a benefit to the sampler as well as some experience in hydrogeology.

PREPARATION AND MOBILIZATION

Before embarking on any sampling run, the sampler(s) should determine what constituents will be tested in the laboratory to allow efficient planning of equipment and material needs. One should also determine if previous sampling results or other site data indicate dangerous/toxic contaminant levels in any of the monitoring wells and arrange for proper protective equipment and clothing. The equipment needed for inorganic sampling includes:

- Suction pump (preferably peristaltic) with eductor tubing, preferably polyethylene.
- Electric submersible pump where required lifts are greater than 25 feet.

- Generator for electric submersible pumps.
- Middleburg type pump (Geotech) and accompanying tubing, regulator, gas and logic unit.
- Teflon bailer.
- PVC bailers (2" and 1-1/2").
- Field filtering unit (Geotech).
- Temperature, pH, Eh, and conductivity probes/meters.
- Water level detector, (M-scope or similar electrical device).
- Extra rope, type?
- Weed wacker type mono filament to use as bailer line (long enough for deepest well).
- Wash/rinse supplies including Ivory Snow or similar detergent, sponges, bottle brushes, portable wash tub, and paper towels.
- Distilled or deionized rinse water, approximately 1 gallon/well.
- Disposable gloves.
- Prefilter and 0.45 micron filters (Schleicher and Shuell #29 and BA 85 or equivalent).
- Tool box with wrenches, screwdrivers, pliers, tape, spare parts, and tape measure marked in feet and tenths.

Additional equipment should be taken into the field when the water will be lab tested for organic constituents:

- Syringe sampler with tubing and vacuum pump.
- Lab grade methanol for equipment cleaning.

The sampler(s) should also examine previous laboratory results or other well data and plan a sampling sequence that progresses from the least contaminated monitoring well to the most contaminated. Such a sampling progression would minimize the possibility of cross contamination. In cases where a well is extremely contaminated with organic sludges, it is advisable to dedicate a bailer to the well rather than using a syringe sampler or Middleburg type pump which are expensive and more difficult to clean.

Also note which wells recover from pumping slowly and plan to initiate well evacuation at those wells first. Where slow recovery, highly contaminated wells exist, the sampler must judge the trade off of field time versus possible cross contamination.

SAMPLING METHODS - WELL EVACUATION

<u>Pore Volume Calculation</u>

1. Measure the depth-to-water with an M-scope or similar device.

2. Compute the height of water in the well by subtracting the depth-to-water from the depth to the bottom of the screened interval.

3. Multiply the height by the appropriate constant to obtain the volume of water in the well. For depth measurements made in feet and for results in gallons, multiply water column height by 1.47 gallons/ft. for 6" diameter wells, 0.37 gallons/ft. for 3" diameter wells and 0.16 gallons/ft. for 2" diameter wells. For example, a 38 foot deep, 3 inch diameter monitoring well with a depth-to-water of 24.52 feet has a pore volume of 4.95 gallons.

EVACUATION PUMP SELECTION TABLE

WELL EVACUATION METHOD	BEST WHEN USED:
Middleburg type pump (e.g. Geotech)	Water table below suction lift when well does not have a permanently installed pump. Used when water level recovery rates are moderate to high. Pump must be completely submerged.
Peristaltic pump	Water table within suction lift. Used on wells that require less than approximately 4 gallons of water removal for adequate evacuation. Good for slow recovery wells.
Centrifugal pump	Water table within suction lift on wells that have moderate to high recovery rates. Cannot be used for sampling.
Bailer, Teflon, stainless steel or PVC	On slow recovery wells and on wells where access is difficult.
4" Electric Submersible pump	On wells where pump is permanently installed or deep large diameter wells where use of low yield pumps not practical.

Pump Cleaning

Before any equipment goes into the well it should be washed and rinsed with distilled or deionized water. For pumps this means thoroughly cleaning the exterior and flushing the pump with distilled water. Bailers are easier to clean especially when a long handled bottle brush is available. Only that portion of the equipment that is going to come in contact with well water needs to be cleaned. If the well has only 15 feet of water, it is not necessary to clean 60 feet of hose.

Well Evacuation

There is no set, or pre-established optimum number of pore volumes that must be evacuated prior to sampling. The pump discharge should be measured so that the sampler knows how many pore volumes have been removed. Some wells recover so slowly that the sampler may find it advantageous to remove a pore volume, move on to another well and return after some time has elapsed.

Research indicates a minimum of 3 pore volumes generally must be evacuated before ground water in the well begins to stabilize chemically and a representative sample can be taken. The sampler(s) should periodically monitor the pH, conductivity and temperature of the ground water during evacuation to determine when it has stabilized. Up to 8 pore volumes may have to be removed before these constituents stabilize and a "representative" sample can be taken.

SAMPLE COLLECTION

Ground water sample collection should take place right after well evacuation. Generally, the same device can be used for sample collection as was used for well evacuation. However, water samples should not be collected with the centrifugal pump because of unacceptable aeration. If a well was evacuated with a centrifugal pump it can be sampled with a bailer or peristaltic pump. Wells evacuated with a peristaltic or Middleburg pump or with a bailer can and probably should be sampled using the same method (except for volatile organics) to save time and avoid the additional chance of possible contamination by introducing more equipment into the well.

When using the Middleburg type pump or bailer, the sample water should be collected in a glass, polyethylene or PVC container (not the bottle provided by the lab) that has been detergent and/or methanol cleaned and then rinsed several times (at least 3) in the previously evacuated well water. Glass containers can be cleaned and reused, but the plastic should be discarded after use.

After collection in a suitable container the sample is filtered through a glass prefilter and a 0.45 micron membrane filter directly into the containers provided by the testing lab (option 1, Figure 1). If the peristaltic pump is used for sample collection water can be pulled directly from the well (rather than a collection bottle) and filtered into the laboratory container (option 2, Figure 1). Samples to be lab tested for volatile organics or bacteria must not be filtered (more on volatile organics sampling later). All samples should be transferred immediately into an ice packed cooler and should be taken to the laboratory within 24 hours.

FIELD FILTERING CONSIDERATIONS

In order to minimize field filtering time, large diameter (142 mm) filters should be used. To filter samples with high clay concentrations a prefilter such as the Schleicher and Schuell #29 glass prefilters should be used. If the prefilter becomes so clogged that flow into the collection bottle is negligible the prefilter should be replaced. The optimal filtering pressure for the membrane filters is about 20 psi; so a low pressure peristaltic pump should be used.

Betweenwells, the filter apparatus should be thoroughly washed and rinsed with distilled water and the prefilter and filter replaced. If organics will be tested then the filter apparatus should be rinsed with methanol between the wash and rinse. In all filtering situations at least 50-100 ml of well water should be run through the peristaltic pump and filter before actual sample collection to flush out any remnants of distilled water.

VOLATILE ORGANICS SAMPLING

Since volatile organics escape rapidly into the atmosphere, the sampler must minimize the sample's exposure to air. One should use a detergent washed, methanol rinsed, distilled water rinsed syringe sampler to collect samples. If a syringe sampler is unavailable a similarly washed Teflon or stainless steel bailer will suffice. After collection the sample is transferred directly into the VOA bottles provided by the testing laboratory. Extreme caution should be used in filling and capping the VOA bottles to prevent any air from being trapped inside them. Bottled samples must be kept on ice and should be delivered to the laboratory within 24 hours.

FIELD WATER QUALITY TESTING

Certain water quality tests can only be made in the field (e.g. temperature)and other field measurements, if properly made, are more accurate than laboratory tests (e.g. electrical conductivity, pH, Eh and DO) due to inevitable chemical changes that take place following sampling. The appropriate methodology for field measurement of the above parameters can vary between instrument manufacturers. Therefore, one should understand the operating principle of the instrument and the manufacturer's recommended procedures for calibration and operation.

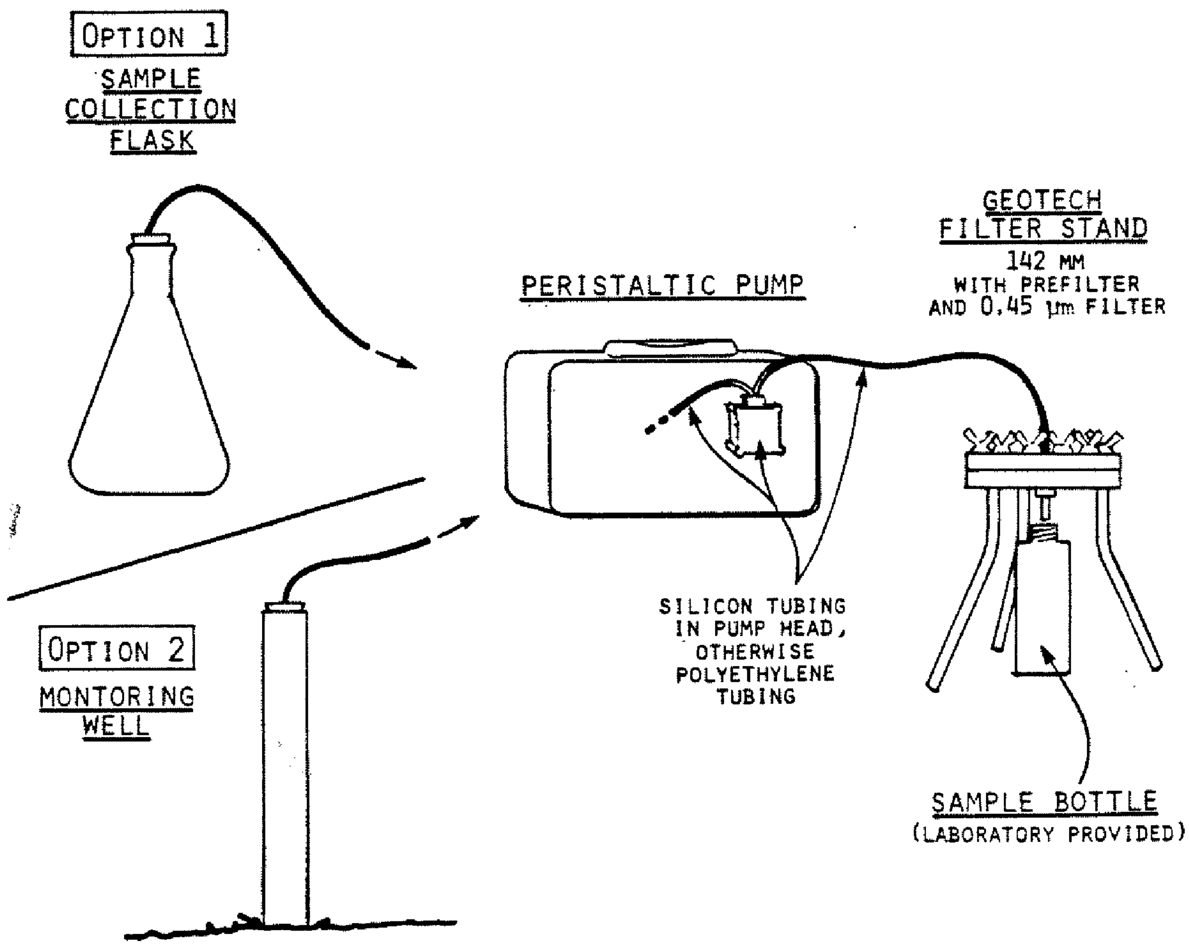

Figure 1. Field Filtration Set-up

APPENDIX F

GROUND WATER STUDIES EVALUATION

GROUND WATER STUDIES EVALUATION

The Duwamish Ground Water Study involved a review of all available reports from both public and private sources which dealt with ground water in the Duwamish Basin. Reports meeting these requirements were available for only six sites in the basin. The locations of several of these sites are shown on Figure III-3 and listed on Table III-1 in this report. Following is a brief summary of relevant facts and conclusions derived from these five reports.

Report No. 1: Titled: "SeaFab Metal Corporation, 2700 16th Avenue SW, Seattle, Washington 98101," date: October 5, 1984; report by: Parametrix Incorporated, Bellevue, Washington.

Four monitoring wells were installed around an inactive surface impoundment at the SeaFab site on Harbor Island to assist in performance monitoring of impoundment closure activities. The letter report did not include any water quality data from the monitoring wells, but some useful ground water hydrology data was included. The impoundment site is approximately 1000 feet from the estuary and ground water table fluctuations caused by tidal effects from the estuary were found to be minimal. A daily tidal fluctuation of approximately 8 feet in the estuary resulted in total fluctuation of the water table at the surface impoundment of less than one tenth of a foot during that time period. These data on tidal influence on ground water table depth are consistent with the results found from monitoring at the Boeing/ Isaacson site.

Report No. 2: Titled: "Renton Effluent Transfer System - Hazardous Waste Site Survey Preliminary Investigations," date: September, 1984; report by: URS Engineers, for The Municipality of Metropolitan Seattle.

Soil samples taken in test borings along the proposed pipeline route were laboratory tested for the presence of hazardous constituents. In addition, monitoring wells were installed adjacent to the closed West Seattle and South Park landfills. Monitoring Well DM-555 near the West Seattle landfill showed the presence of volatile organics, acid base neutral organics, and pesticides. Two other nearby wells showed similar water quality. Monitoring well DM-329 near the South Park landfill showed the presence of selected pesticides, volatile and non-volatile organics. Their report did not include any site specific ground water hydrology information.

Report No. 3: Titled: "Hydrogeologic Study, ChemPro Georgetown Facility, Seattle, Washington," date: February 1983; report by: Hart-Crowser and Associates for Harper-Owes.

This study included the installation of ten monitoring wells onsite. Field testing of the site monitoring wells to obtain aquifer parameters was conducted. Site monitoring wells were sampled and laboratory tested to obtain water quality data. The site is located approximately 4000 feet east of the Duwamish River. The study results show that organic chemical compounds have entered the ground water from the facility. The rate of ground water flow was estimated to range from 0.45 to 1.0 feet per day. The average site water table gradient was measured to be 0.0037. Monitoring wells installed at varying depths in the aquifer show a net upward hydraulic gradient at the site. The average horizontal permeability in the upper sand at the site was measured at 1×10^{-2} cm/sec. The average horizontal permeability in the lower silty fine sand and silt was determined to be 1.6×10^{-5} cm/sec. Contamination of ground water by the organic compounds was measured to a maximum depth of approximately 54 feet below ground surface. Ground water flow is toward the Duwamish River. Contaminants being transported by ground water from the facility are estimated to reach the Duwamish River between 10 and 25 years after leaving the site.

Report No. 4: Titled: "Monitoring of Ground Water Surrounding an Upland Disposal of PCB-Contaminated Dredged Materials," dated: January 7, 1985; report by: The Port of Seattle Planning and Research Department.

A dredge spoils disposal pit was excavated at Terminal 105 west of the Duwamish. The pit was designed to hold approximately 16,000 yards of dredge spoils. Land disposal of the dredge spoils from the Duwamish estuary was required by the Corps of Engineers because testing of the spoils had shown the presence of selected organic and inorganic contaminants. Prior to placement of the dredge spoils, three monitoring wells were installed around the perimeter of the disposal pit. The depth to ground water at the pit location ranged from 4 to 8 feet. Ground water samples from the three monitoring wells were sampled and tested prior to and following placement of spoils in the pit. Saline intrusion into the aquifer near the pit resulted in variable salinity values in ground water samples from the monitoring wells. Water quality data from the three monitoring wells showed significant concentrations of phenols, selected pesticides, and the following inorganics: arsenic, cadmium, chrome, copper, lead, cyanide, and zinc. These constituents resulted from dewatering of the dredge spoils.

Only the zinc and copper concentrations in ground water exceeded the Salt Water Aquatic Life Standards. The chrome and lead concentrations in ground water decreased significantly in the downgradient direction away from the disposal pit, whereas the other inorganic constituent concentrations listed above increased in concentration downgradient of the disposal pit. Although not stated in this report, it is likely that the reduction in chrome and lead concentration was due to precipitation of these metals at the saline water interface.

Field testing of the site monitoring wells showed an average hydraulic conductivity of 1.4×10^{-2} cm/sec., with an average ratio of horizontal to vertical permeability estimated to be 150:1. Ground water flow at the site is toward the Duwamish estuary.

Report No. 5: Titled: "Evaluation of Potential Soil and Ground Water Contamination at the Isaacson Corporation Property, Seattle, Washington," date: November 22, 1983; report by: Patrick H. Wicks, PE, Redmond, Washington, and Sweet, Edwards and Associates, Kelso, Washington; for: Isaacson Corporation, Seattle, Washington.

During this study, eight ground water monitoring wells were installed at the Isaacson site. Field testing and ground water sampling of the wells was conducted to determine aquifer parameters and ground water quality. Following is a summary of results and conclusions on site hydrology and water quality which are relevant to the Duwamish study.

1. Ground water at the site occurs under water table or unconfined conditions and the water table surface is generally less than 15 feet below ground.

2. Ground water in the eastern portion of the site flows from east to west toward the Duwamish River. In the western portion of the site, flow is northwest and in a downriver direction at low tide and southeast away from the river at high tide.

3. Water table gradients vary greatly from east to west onsite because of tide influenced water table fluctuations.

4. Semi-impervious surfaces at the site, including roofs, asphalt, and concrete, probably result in very little direct recharge to ground water at the site.

5. Arsenic concentrations measured in ground water during the study exceed the EPA Primary Drinking Water Standard Maximum Contaminant Level.

6. Chromium, copper, lead, and zinc were also detected in ground water at the site, but at levels below the EPA Drinking Water Maximum Contaminant Levels.

7. Water quality data from monitoring wells 7 and 20 indicate that a limited area of the western portion of the site contains saline ground water of marine origin.

8. Definition of the lateral and vertical extent of contaminated ground water are complicated by tidal fluctuations and saline ground water in the western portion of the site.

9. There were not sufficient data available for the study to predict the fate of heavy metal contaminants in site ground water. A natural onsite attenuative mechanism may exist at the interface between the heavy metal contaminated ground water and the saline ground water.

10. The water table gradients on the western portion of the site, which are influenced by tidal fluctuations in the Duwamish River, ranged from approximately .001 to .004 feet per foot, more than four times higher than those found on the eastern portion of the site.

Subsequent to this study, six monitoring wells on the Isaacson site were field tested to determine aquifer permeability. The average permeability derived from these tests was approximately 3.5×10^{-1} cm/sec. Depending upon the influence of tidal fluctuations on the water table gradient, ground water flow rate of 3-6 feet per day was determined for the site shallow aquifer.

Report No. 6: Titled "Summary Report Ground Water Sampling and Monitoring Interim Status Dangerous Waste Pile Facility, Seattle Steel Corporation, Seattle, Washington," dated October, 1984; report by Applied Geotechnology, Inc., Bellevue, Washington for Bethlehem Steel Corporation, Seattle, Washington.

This study focused on water quality monitoring and ground water investigations at Bethlehem's 1/4 acre waste pile facility approximately 2600 feet west of the river. Prior to 1982, electric arc furnace flame trap sludges were disposed of at the facility. Four monitoring wells were installed in 1981 upgradient and downgradient of the facility. The monitoring wells were screened in the uppermost aquifer. In 1984 nine test pits were dug, five of which were converted to piezometers. In addition, continuous water level recorders were maintained in the four monitoring wells and a storm drainage ditch east of the site.

A localized perched ground water system was identified above a clay fill deposit and a confined ground water system was identified below the clay fill. Ground water flow is west to east with the possibility of discharge to the storm drainage ditch. A slight tidal influence was observed in the monitoring wells (maximum 1/2 foot in the monitoring well closest to the river during 13 foot tide fluctuation).

Cadmium and lead were the ground water quality parameters of concern in this study. The monitoring wells yielded cadmium concentrations of .002-.005 mg/L from unfiltered samples in 1982, and .001 mg/L or less from filtered samples in 1984. Concentrations of .05 mg/L or less were obtained from test pit filtered samples.

The monitoring wells yielded lead concentrations of .02 mg/L or less from unfiltered samples in 1982, and less than .05 mg/L from the 1984 filtered samples. Concentrations of lead in filtered test pit samples ranged from .26-.79 mg/L.

Concentrations of both lead and cadmium are higher in the perched aquifer (accessed by test pit) than in the confined aquifer (accessed by monitoring well) indicating attenuation of the contaminants by the clay fill.